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Sustainable refurbishment of exterior walls and building facades

Final report
Part A – Methods and recommendations

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Final report, Part A – Methods and recommendations

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Sustainable refurbishment of exterior walls and building facades

Final report, Part A – Methods and recommendations

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Abstract

This report is the final report of Sustainable refurbishment of building facades and exterior walls (SUSREF).

SUSREF project was a collaborative (small/medium size) research project within the 7th Framework Programme of the Commission and it was financed under the theme Environment (including climate change) (Grant agreement no. 226858).

The project started in October 1st 2009 and ended in April 30th 2012.

The project included 11 partners from five countries. The coordinator of the project was Tarja Häkkinen, VTT.

SUSREF developed sustainable concepts and technologies for the refurbishment of building facades and external walls. This report together with SUSREF Final report Part B and SUSREF Final Report Part C introduce the main results of the project. Part A focuses on methodological issues. The descriptions of the concepts and the assessment results of the developed concepts are presented in SUSREF Final report part B (General concepts) and SUSREF Final report Part C (Specific concepts).

The following list shows the sustainability assessment criteria defined by the SUSREF project:

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.

This report gives guidelines for the use of assessment methods especially regarding durability and life cycle impacts.

The report also gives recommendations for sustainable process management, recommendations for building industry, and recommendations for standardization bodies and policy makers.

With regard to process management, it was concluded that the process would benefit from a Requirements Specification meeting early in the project so that all stakeholders are aware of the agreed needs and requirements of the occupants, funders, owners etc. from the outset. A Sustainability Workshop should be held towards the end of the Defining Performance Criteria stage to agree targets and benchmarks. The reason for having workshop during that stage is because most of the stakeholder groups are involved and so it will be viable to agree targets with input from most of them. There is an opportunity to have another Sustainability Workshop at the beginning of Construction stage to check on the agreed targets and benchmark has been followed. Also changes to the other issues should be raised during this project stage. Further Sustainability Workshops should be arranged for later parts of the process. It is also essential for projects to be monitored once they have been handed over to the clients and occupants. This is underlined by the often ‘experimental’ nature of many refurbishment solutions, which need to be assessed in use.

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.

Regarding 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.

Regarding 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.

Regarding 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.

Regarding 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.

Regarding 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.

Regarding relevant standardisation, SUSREF project concluded that recommends that the standards developed by CEN TC 350 are applicable for new building over their entire life cycle and for existing buildings over their remaining service life and end of life stage and are usable also for the cases of refurbishment assessment as they are. Also the standards developed bu ISO TC 59 / SC 17 (Sustainability in building construction) are valid for building operation, for retrofitting and refurbishment and can be used for benchmarking performance and monitoring progress towards improvement and sustainable development.

Regarding Service life planning standards developed by ISO, it was concluded that 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. 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.

Regarding life cycle costing, it was concluded that the most problematic part of Life cycle costing in case of extensive renovations is management of risks. It would be important to create a European guide for better risk management.

SUSREF project recommends the development of a new Euro code which takes into account refurbishment aspects of building envelope and frame. The project recommends the development of a Euro code "Design for refurbishment of external walls" which describes design methods and performance criteria.

Recommendation is also 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.

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.

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
(b) reinforcement of informative support and dissemination of information
(c) development of effective incentives for sustainable refurbishment of exterior walls
(d) promotion of training for improved expertise in design and construction of sustainable refurbishment concepts
(e) continuous support for demonstration
(f) better citizen engagement.

Keywords Refurbishment, exterior walls, sustainable building, assessment method

Preface

This report is the final report of Sustainable refurbishment of building facades and exterior walls (SUSREF).

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The project started in October 1st 2009 and ended in April 30th 2012.

The project included 11 partners from five countries:

VTT Technical Research Centre of Finland	VTT	Finland
Stiftelsen SINTEF	SINTEF	Norway
Vahanen Oy	Vahanen	Finland
Cardiff University (CU)	CU	UK
Building Research Establishment	BRE	UK
TECNALIA	TECNALIA	Spain
Repair Estructuras S.L.	Repair	Spain
Oneka Architectura S.L.	ONEKA	Spain
Sustainable Gwynedd Gynaladwy Cyf	SGG	UK
Ehituskonstrueerimise ja Katsetuste OU	EKK	Estonia
Trondheim og omegn boligbyggelag	TOBB	Norway

The coordinator of the project was Dr. Tarja Häkkinen, VTT.

SUSREF developed sustainable concepts and technologies for the refurbishment of building facades and external walls. This report together with SUSREF Final report Part B and SUSREF Final Report Part C introduce the main results of the project. Part A focuses on methodological issues. The descriptions and assessment results of the developed concepts are presented in SUSREF Final report part B (generic concepts) and SUSREF Final report Part C (SME concepts).

The main objectives of the SUSREF project were:

– to identify and understand the quantitative needs to refurbish building envelops in the EU and neighbouring areas; to understand the meaning of these needs, in the first place, in terms of environmental impacts and secondly in terms of financial impact and business potential;

- to develop a systemized theory and different technologies for refurbishment of building facades and external walls in order to ensure the functional excellence of solutions; to analyse technologies from the view point of building physics and energy efficiency; to consider the various challenges in different parts of Europe in terms of present climate, technological differences, and cultural-historic differences; and finally to deliver sets of relevant performance specifications for sustainable refurbishment;
- 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;
- to develop sustainable concepts for carrying out refurbishments projects;
- 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.

All deliverables are available on SUSREF web site http://cic.vtt.fi/susref/

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List of abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CH_4	methane
CHP	combined heat and power production
CO_2	carbon dioxide
CO_{2e}	carbon dioxide equivalent calculated on the bases of GWP of GHGs
CTF	conduction transfer function
ELCD	European Reference Life Cycle Database
EOTA	European Organisation for the Technical Approvals
EPD	Environmental product declaration
ETA	European Technical Approval
EPBD	Energy Performance in Buildings Directive
EPD	Energy Performance Directive
EPS	Expanded Polystyrene
ETA	European Technical Approval
ETICS	external thermal insulation composite systems
GHG	greenhouse gas
GWP	global warming potential
HAMT	heat, air and moisture transfer
HDD	heating degree days
HVAC	heating, ventilation, and air conditioning
IEA	International Energy Agency
IPCC	International panel on climate change
LCA	life cycle assessment

LCC	life cycle costing
LCI	life cycle inventory
LHV	lower heating value (net calorific value)
N_2O	nitrous oxide (laugh gas)
NMVOC	non-methane volatile organic compound
PC	polycarbonates
PCM	phase-chancing material
PF	phenolic foam
PM	particulate matter
PMMA	polymethyl methacrylate
PU	polyurethane
PV	photovoltaic
SO_2	sulphur dioxide
SUSREF	Sustainable refurbishment of exterior walls and facades
TOW	time of wettness
WHO	World Health Organization
VIP	vacuum insulation panel
VOC	volatile organic compound

1 Introduction

SUSREF research project focused on the development of sustainable concepts and technologies for the refurbishment of building facades and external walls.

The project was based on the premise that

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) Because of the age of the European building stock, building owners and the whole building sector face a challenge of extensive refurbishments. 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 problems caused by energy renovation of buildings, the new concepts and solutions cannot be used without achieving a comprehensive understanding about the building physical behaviour, energy efficiency, environmental impacts, and life cycle costs.
4) External walls have an essential 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 for good building refurbishment methods is not only faced in the EU but also – and 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 quality of the building stock, various building technologies, 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 common efforts for environmental innovations and export. The theory of building physical behaviour of external walls, and the principal effects of external walls on building performance and energy efficiency are common, although the relevant and optimal solutions differ.

The main objectives of the project were

- to identify and understand the quantitative needs to refurbish building envelops in the EU and neighbouring areas; to understand the meaning of these needs, in the first place, in terms of environmental impacts and secondly in terms of financial impact and business potential;
- to develop a systemized theory and different technologies for refurbishment of building facades and external walls in order to ensure the functional excellence of solutions; to analyse technologies from the view point of building physics and energy efficiency; to consider the various challenges in different parts of Europe in terms of present climate, technological differences, and cultural-historic differences; and finally to deliver sets of relevant performance specifications for sustainable refurbishment;
- 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;
- to develop sustainable concepts for carrying out refurbishments projects;
- 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.

This report presents the main methodological results of the project. The report includes 8 Chapters, which introduce the developed methods, assessment results, guidelines and recommendations as follows:

Chapter 1 presents the objectives and starting points of the project.

Chapter 2 gives background information about the European building stock, European climate, and renovation methods of exterior walls.

Chapter 3 introduces the sustainability assessment concept developed within SUSREF. Chapter 3 also presents and gives guidelines about the use of different assessment methods. These include energy assessment methods, building physical assessment methods and life cycle assessment methods.

Chapter 4 present introduces alternative refurbishment concepts based on the study of literature.

Chapter 5 presents the energy saving potential of the refurbishment of walls on the basis of literature.

Chapter 6 presents the calculation results about the effect of different refurbishment scenarios on environmental and economic impacts on European level.

Chapter 7 assesses the impact of building refurbishment on energy consumption building level in different European conditions.

Chapter 8 gives guidelines and recommendations for processes management, building industry, standardisation bodies and for policy makers.

2 European building stock, European climate, renovation needs and methods of exterior walls

2.1 European building stock

This section gives summarized information about the European building stock. On the bases of EUROSTAT information over half of the residential buildings in Europe are single family houses (53%), while the share of multi-family buildings is 37% and the share of high-rise buildings is 10% (calculated by the number of dwellings).

The following table shows the share of old and intermediate buildings and the share of single-family and multi-family buildings in different European countries.

Table 1. *Share of different aged and types of buildings in Europe.*

in % of all residential dwellings	Old buildings (< 1975)	Intermediate Buildings (1976–2004)	Share of single-family buildings (existing buildings)	Share of multi-family buildings (existing buildings)
Austria	48	52	56	44
Belgium	79	21	70	30
Bulgaria	86	14	56	44
Croatia	47	53	56	44
Cyprus	38	62	43	57
Czech Republic	33	67	42	58
Denmark	72	28	59	41
Estonia	60	40	25	75
Finland	53	47	54	46
France	61	39	57	43

in % of all residential dwellings	Old buildings (< 1975)	Intermediate Buildings (1976–2004)	Share of single-family buildings (existing buildings)	Share of multi-family buildings (existing buildings)
Germany	81	19	47	53
Greece	55	45	43	57
Hungary	46	54	61	39
Iceland	56	44	76	24
Ireland	46	54	92	8
Italy	71	29	29	71
Latvia	64	36	25	75
Liechtenstein	43	57	56	44
Lithuania	64	36	25	75
Luxemburg	49	51	70	30
Malta	63	37	82	18
Netherlands	57	43	70	30
Norway	65	35	76	24
Poland	47	53	33	67
Portugal	43	57	50	50
Romania	82	18	56	44
Slovakia	31	69	49	51
Slovenia	69	31	36	64
Spain	62	38	50	50
Sweden	71	29	43	57
United Kingdom	71	29	81	19

Source: Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries, Karlsruhe/Grenoble/Rome/Vienna/Wuppertal, 15. March 2009 (Anon 2009).

The following Table presents information about the average living space in different European countries. It varies between 22 (in Poland) and 51 (in Denmark).

Table 2. Population growth, number of dwelling stock and living space. Source IMPRO (Nemry et al. 2008).

Country	Population growth 1990 to 2004 in %	Dwellings stock in 2003 millions	Dwellings per 1 000 inhabitants in 2003	Living space per person in 2004 in m^2	Completion per 1 000 inhabitant in 2003
Austria	5.8	3 904	477	38	5.2
Belgium	4.5	4 820	463	36	3.9
Denmark	5.1	2 541	471	51	4.4
Germany	4.3	38 935	472	40	3.2
Finland	4.9	2 574	492	36	5.4
France	5.9	29 495	490	38	2.6
Greece	9.1	5 465	494	30	11.6
United Kingdom	3.6	25 617	429	44	3.2
Ireland	14.8	1 554	385	35	17.4
Italy	1.4	26 526	461	32	3.1
Luxembourg	19.0	176	391	50	3.6
The Netherlands	9.2	6 811	418	41	3.7
Portugal	5.6	5 318	506	29	7.9
Sweden	5.3	4 329	482	44	2.7
Spain	5.5	20 823	488	31	11.3
Total EU-15	4.7	178 888	467	37	5.1
Poland	0.4	11 763	308	22	4.3
Slovakia	1.8	1 885	350	26	2.6
Slovenia	0.1	785	393	30	3.7
Czech Republic	-1.5	4 366	436	29	2.7
Hungary	-2.5	4 134	409	28	2.1
Total CEE5[a]	-0.2	22 933	349	25	3.5

[a)] CEE5 aggregates the five countries in Central and Eastern Europe: Czech Republic, Slovakia, Hungary, Poland and Slovenia.

The following table shows the age distribution of the housing stock in the EU-25 countries. Approximately 14% of buildings has been built before 1919, 12% during 1919–1945, 32% during 1946–1970, 20% during 1971–1980 and finally 22% after 1981.

Table 3. Age distribution of housing stock.

Year	Year	Population 2008 (EU 2009) x10^3	Number of dwellings, millions	Total area per person, m^2	<1919	1919–1945	1946–1970	1971–1980	1981–1990	>1990
Austria	**2003**				18.6	8.1	27.4	15.9	12.4	17.6
Belgium	2004	10667	4.8	86.3	15.0	16.5	29.0	15.2	9.2	15.1
Cyprus	2001				n/a	7.4	16.9	20.7	27.4	27.1
Czech Republic	2001	10381	4.3	76.3	10.9	14.7	26.3	22.5	16.4	8.2
Denmark	2003	5476	2.6	109.1	20.2	16.9	28.3	17.6	9.7	7.4
Estonia	2003	45283	20.9	90.0	9.4	14.2	30.0	21.5	19.6	5.3
Finland	2002	5300	2.6	77.0	1.6	8.8	30.6	23.4	20.0	14.4
France	2002	61876	29.5	89.6	19.9	13.3	18.0	26.0	10.4	12.4
Germany	2002	82218	38.9	89.7	14.6	12.6	47.2	10.9	14.6	n/a
Greece	2001	1341	0.6	60.2	3.1	7.2	31.8	24.5	19.1	14.3
Hungary	2001	10045	4.1	75.0	13.9	12.5	26.1	22.3	17.7	7.4
Ireland	2002	4401	1.4	104.0	9.7	8.2	16.4	17.5	16.2	31.9
Italy	1991	59619	26.5	90.3	19.0	10.5	40.7	19.7	10.1	n/a
Latvia	2002	2271	1.0	55.4	11.0	13.8	27.7	22.6	21.1	3.7
Lithuania	2002	3366	1.3	60.6	6.2	23.3	33.1	17.6	13.5	6.3
Luxembourg	2001	484	0.2	125.0	11.9	14.8	27.0	17.9	11.6	17.1
Malta	2002				14.9	11.0	29.4	16.9	15.8	11.8
Netherlands	2002	16405	6.8	98.0	7.1	13.2	30.9	18.9	29.8	n/a
Poland	2002	38116	11.8	68.2	10.1	13.1	26.9	18.3	18.7	12.9
Portugal	2001	10618	5.3	83.0	5.9	8.5	22.9	18.3	44.4	n/a
Slovakia	2001	5401	1.7	56.1	3.4	6.6	35.1	25.6	21.0	6.8
Slovenia	2002	2026	0.8	76.0	15.3	7.9	28.1	23.6	16.2	8.7
Spain	2001	45283	20.9	90.0	8.9	4.2	33.5	24.1	13.6	15.7
Sweden	2003	9183	4.4	91.6	12.4	20.2	33.1	17.4	9.7	7.2
United Kingdom	2001	61186	25.6	86.9	20.8	17.7	21.2	21.8	18.5	n/a

Source: Housing Statistics in the European Union 2004 (National Board of Housing, Building and Planning, Sweden, Ministry for Regional Development of the Czech Republic).

CE25 (Koukkari & Braganca 2009) report indicates (Table 1) that the number of dwellings in EU-27 is about 215 million, of which about three fourths is located in six countries: Germany (18.0%), Italy (12.3%), UK (11.9%), France (13.7%), Spain (9.7%), and Poland (5.5%).

IMPRO project (Nemry et al. 2008) developed a typology of the residential buildings in the 25 EU countries (EU-25). The country specific statistical data was divided in three groups: single-family houses (including two-family houses and terraced houses), multi-family houses and high-rise buildings as follows:

1) Single-family houses (SI) include individual houses that are inhabited by one or two families. Also terraced houses are assigned to this group
2) Multi-family houses (MF) contain more than two dwellings in the house
3) High-rise buildings[1] (HR) were defined as buildings that are higher than 8 storeys[2].

The building data was divided into three categories based on the climatic conditions (long term average of the heating degree days (HDD) during the period 1980–2004). The division of the European countries into three climate zones is presented in the following Table.

Table 4. *European building stock.*

	Country	HDD	Population in 2003 (million)	Building stock (million m^3)
Zone 1: Southern European Countries 564 to 2 500 HDD (1 269 HDD)[a] 	Malta	564	0.40	11
	Cyprus	787	10.41	337
	Portugal	1302	10.41	337
	Greece	1698	11.01	351
	Spain	1856	41.55	1 454
	Italy	2085	57.32	2 076
	France	2494	59.64	2 109
Zone 2: Central European Countries 2 501 to 4 000 HDD (3 272 HDD)	Belgium	2882	10.36	359
	The Netherlands	2905	16.19	561
	Ireland	2916	3.96	125
	Hungary	2917	10.14	221
	Slovenia	3044	2.0	45

1 The definition of “high-rise building” differs from one country to another. In Estonia, for instance, a high-rise building has at least 14 storeys whereas, in south European countries, high-rise buildings are defined as having more than five storeys.

2 One special building type, the panelised buildings, is found in most (especially eastern European) countries. In literature and statistics, they are either accounted for high-rise buildings or multi-family buildings. In the EU-25, altogether 34 million dwellings or 17% of the whole buildings stock are included in panel buildings.

	Country	HDD	Population in 2003 (million)	Building stock (million m^3)
	Luxembourg	3216	0.45	21
	Germany	3244	82.54	3 463
	United Kingdom	3354	59.33	1 567
	Slovakia	3440	5.38	82
	Denmark	3479	5.38	230
	Czech Republic	3559	10.20	237
	Austria	3569	8.10	292
	Poland	3605	38.22	706
Zone 3: Northern European Countries 4 000 to 5 823000 HDD (4 513 HDD) 	Lithuania	4071	3.46	62
	Latvia	4243	2.33	45
	Estonia	4420	1.36	28
	Sweden	5423	8.94	338
	Finland	5823	5.21	151

[a] Number in brackets indicates average weighted HDD. Source [EUROSTAT 2005a. Gikas & Keenan 2006]. Source: IMPRO (Nemry et al. 2008).

2.2 External walls

2.2.1 Needs of refurbishment

In Northern Europe the most typical external wall and facade structures are made of wood. Humidity is the most important aspect which must be taken into account when the refurbishment of external walls is executed. Wooden external walls are mainly composed of structures which may be vulnerable for rot and mould, for example load bearing timber frame, thermal insulation and wooden wind barriers. Therefore the rot of wood and emergence of mould in wood and insulation must be prevented.

In Eastern European countries, large element panel constructions are the most in need of renovation. The aim of refurbishing these buildings is to reduce thermal conductivity by eliminating thermal bridges. Otherwise there may be a risk for condensation and mould growth which affects the efficiency of the external wall which in turn reduces the internal thermal comfort experienced by the occupants.

With regard to un-rendered or unclad, solid masonry walls which are exposed to rain penetration, rainwater can penetrate to outer layers under certain conditions of driving rain. This can lead to increased moisture content which can also reach inner layers and result in reduced thermal performance. Problems associated with rain penetration can usually be resolved by the application of an externally applied insulation system protected either by a ventilated rain-screen or a render system.

In European countries with warmer climates, masonry cracks, dampness and external wall instability are the main areas which require renovation attention. Although large numbers of stock in these countries are poorly insulated, according to current standards, potential rises in the global temperature should be considered when considering renovation. Excess insulation in these climates may cause lack of heat dissipation.

Some of the major obstacles to overcome when planning facade renovation in Europe are as follows.

The form of the dwelling ownership can be problematic. In some countries each owner is responsible for their own dwelling repairs. Therefore finding sufficient finances can be a problem. In addition, sustainable refurbishment can be difficult to execute, because the form of the dwellings' ownership limits the refurbishment methods.

Regulations can be a strong barrier to break through to achieve energy efficiency in dwelling refurbishment. Also, a complex property structure, temporary relocation of dwellers and the need for broad agreements in collective dwellings all add the problems of executing façade renovations. Because some of the dwellings owners are not even known, there can be problems finding suitable financiers who will finance the façade renovations of residential buildings.

It is common that dwellings must be refurbished in accordance with the local street plan which gives rules regarding building design, height, slope of roof, roof and façade materials. The main purpose is to maintain good built environment but sometimes these rules may also limit possibilities to carry out modifications which might be needed from the energy saving or technical point of view.

Also the owners of public buildings and residential communities can be an obstacle because of unwillingness to provide financing. In the case of blocks of flats some active groups may slow down refurbishment activities, because of lack of knowledge about long term advantages and emphasis on short-term housing solutions. It is possible that repair solutions available do not support sustainable development if the structure is listed and, therefore an affordable and practical solution cannot be done.

The main type of dwelling in Europe is a single family house which makes up 53% of the total EU-25 residential stock. The remaining 47% is made up of larger houses like multi-family houses and high-rise buildings.

In Northern European countries (Finland, Norway etc.) the most common type of dwelling is a detached single family house. The most popular façade material is timber cladding with an air cavity between the timber cladding and the thermal insulation.

In Eastern European countries and Russia, pre-fabricated high-rise or multi-family dwellings are the most common type of residential buildings. Typically approximately 70% of the dwelling stock in these countries is made of these types of buildings. The main facade types are load bearing sandwich panel systems. Sometimes also non-load bearing systems have been used.

In Southern European countries (Spain, Italy etc.) the single family building is the most common, and a high percentage of those are 1 or 2 storey buildings. The majority of these have facades which are made of different variations of brick cavity walls, concrete blocks and stone walls.

The UK and Central European countries have a mix of different kinds of residential dwelling façade types. There is no one type which dominants greatly over others. Brick, concrete and timber frames are all popular in certain areas.

The majority of the current European residential building stock was built during 1940–1970's. Although most countries in the EU have had some kind of construction boom after or during the 1980's where they have built at least as many dwellings as during 1940–1970's, these dwellings are typically of a higher standard and of course newer.

It should be expected that dwellings built around 30–70 years ago should be the ones in most need of renovation.

In conclusion, there should be two focal points for the SUSREF research:

- Detached, semi-detached and terraced single or multi-family buildings with a façade cladding of timber, brick, stone and concrete, with and without a cavity from the period 1940s–1970s.
- Multi-family buildings/high rise buildings with a façade type of insulated sandwich panel system, both bearing and non-load bearing, from the period 1940s–1970's.

2.2.2 Existing European external wall types

Wooden houses are the most dominating building type in Northern Europe, including Norway and Finland. They are mainly formed with multi-layered walls with a load bearing timber frame which is insulated in most cases. In addition, the use of a wind barrier – separated from the usual wooden cladding by a cavity in the external wall – is very common. The next figure illustrates typical wooden exterior walls.

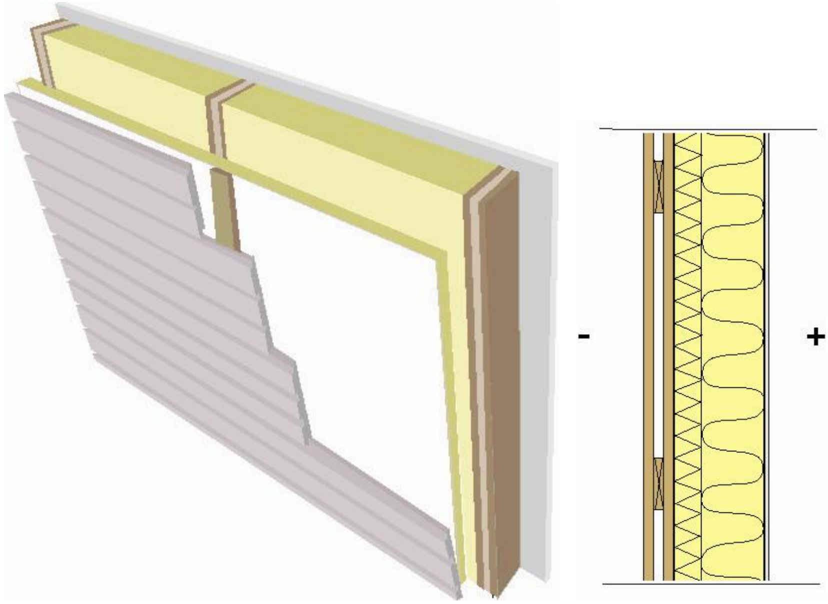


Figure 1. *Wooden façade construction.*

For residential single family and terraced houses, on-site, wooden load bearing frame is the most common method of construction with wooden external wall construction also being the most popular. This is the traditional method but increasingly modern prefabrication techniques are being developed and more self-builders and developers are using this option. Prefabricated panels can offer huge time savings when trying to make a building weatherproof during the construction phase. In the case of high-rise buildings, a concrete load-bearing structure with a concrete/sandwich element panel to clad the exterior is the most common construction technique.

A load bearing, external 3-layer panel is the most common external wall type in Estonia. Approximately 50% of all high rise buildings are built using this structure as an external wall. These types of load bearing or non-load bearing sandwich elements are also popular in the Nordic countries and in Eastern Europe and Russia. The next figure shows an example of a 3-layer panel system.

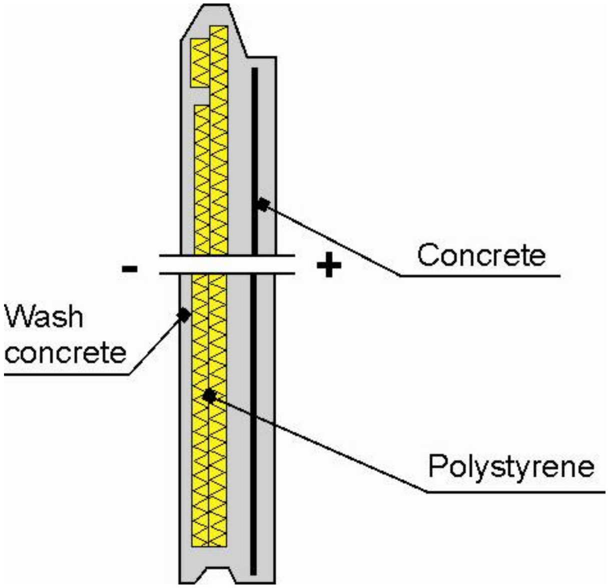


Figure 2. Figure 3-layer panel system

In Spain the majority of the building stock is constructed from reinforced concrete structures with non-load bearing facades. The material types which have frequently been used for facades are brick skins with cavities and concrete blocks. A common material used in older buildings is a stone or a brick load bearing facade. In Spain the most predominant external wall types are stone walls, single leaf brick walls, cavity walls and concrete block walls.

In the Spanish building stock the most common facade types are different variations of brick cavity walls. These are mostly pre 1960s constructed buildings with reinforced concrete structure. The estimated portion of these kinds of facades is 75% of the building stock. When the first thermal performance regulation was taken into use in Spain in 1979, the different combinations of hollow and solid bricks were predominantly non load bearing structures with insulated cavities.

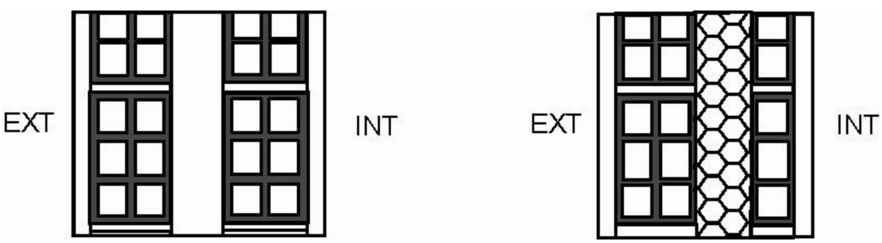


Figure 3. Cavity walls.

The following wall types were here defined as typical:

Typical wall structure 1 – Load bearing wooden wall

Wooden exterior wall (see the next figure) is typical in Northern European housing but is also widely used in central Europe in milder climates. Common features which apply to all countries and varying conditions are that the construction needs an air cavity to let the structure breathe, thermal insulation (specified according to local conditions), breather membrane (to protect the insulation from water vapour but also allowing it to breathe) and an exterior rain-screen panel. This method is primarily used in residential constructions but it is also applicable in other buildings.

In Northern European countries, the most popular external wall type is a non-load-bearing wooden façade. This external wall solution is normally used with an air cavity in order to avoid moisture problems. Less popular, but still used are masonry cavity walls. These are very similar to those used in the UK and other European countries with a moderate climate. They are built with thermal insulation and with an air cavity.

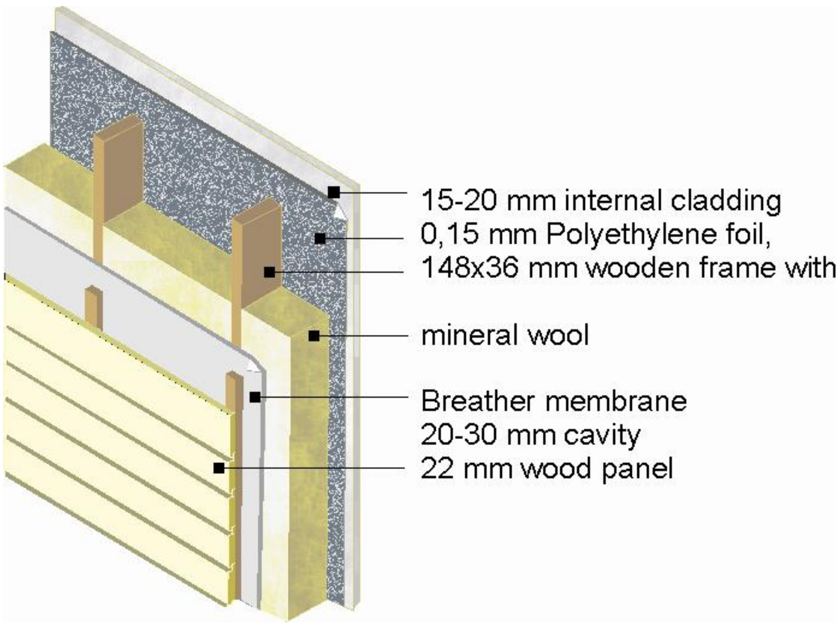


Figure 4. Wooden wall construction.

Typical wall structure 2 – Non load bearing sandwich panel

Non-load bearing sandwich panel (see the next figure) is used predominantly in Eastern European countries in high-rise buildings. It has also had quite widespread use in Finland. It is quick to build on site, various sizes are possible and its performance can easily be modified by changing the thickness of insulation layer to suit to different conditions. Although the original versions may be high in cement content, manufacturers can create modern panels which require less thickness and thus also less concrete and are also able to offer panels cladded with metal or wood, for example.

This type of wall structure still has big potential due to the fact that it can be mass produced easily, can suit to many different conditions by altering the amount of insulation and it's quick in terms of construction time.

In Estonia a load bearing 3 panel/insulated panel system with a pebble dash (rip-rap) finish is the most common external wall type covering approximately 50% of the residential building stock. Russia and other Eastern European countries have also a large percentage of buildings with similar type of external wall in their residential building stocks.

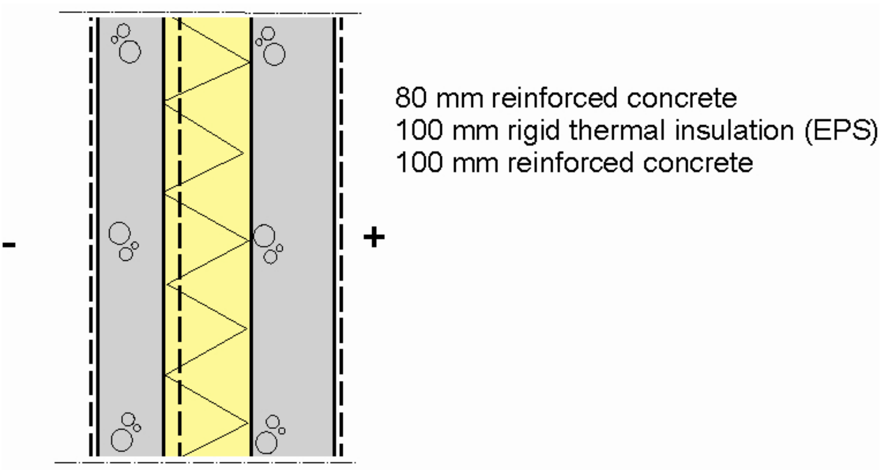


Figure 5. Figure sandwich panel.

Typical wall structure 3 – Loadbearing cavity wall

In both the UK and Spain there is a large percentage of the building stock which is made by using cavity walls – both insulated and non-insulated (see the next figures). In both countries the majority of the stock is originally made up of the non-insulated variety as building regulations changes relating to thermal performance only came into effect in the 1980's in both countries.

Masonry cavity walls are the most common external wall type in the UK with approximately 70% of the residential stock constructed using this method. However, unlike the Spanish masonry cavity walls, a higher percentage of the UK walls has some kind of thermal insulation, due to the difference in climate.

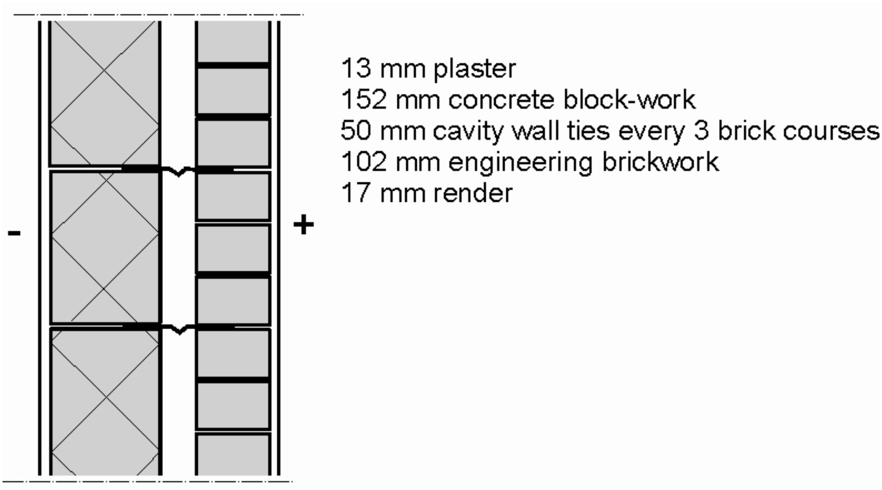


Figure 6. Figure load-bearing cavity wall without insulation.

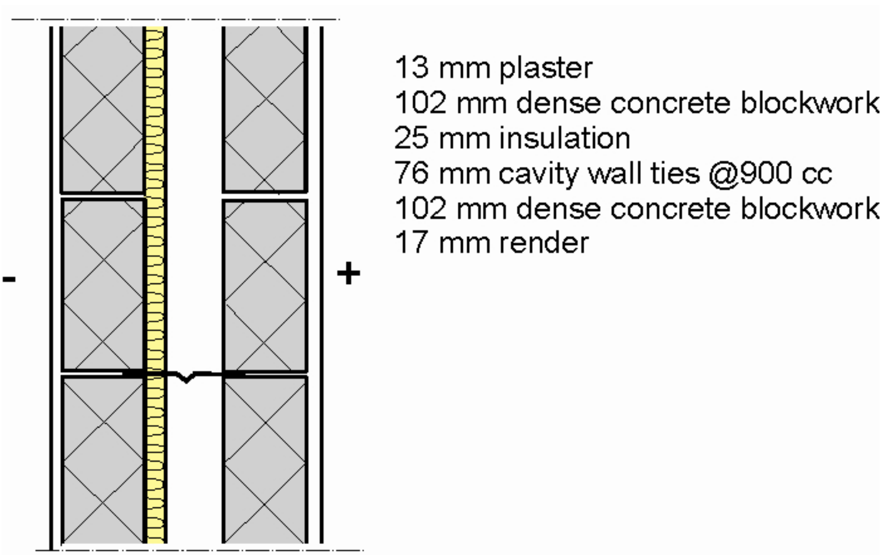


Figure 7. Loadbearing cavity wall with insulation.

Typical wall structure 4 – Non-loadbearing cavity wall

In Spain the majority of cavity walls are non-load bearing walls (see the next figures).

In the Spanish residential building stock the most common external wall types are different variations of brick cavity walls, with a reinforced concrete main structure. The estimated proportion of these kinds of facades is 75% of the building stock. These are predominately built without any thermal insulation as thermal performance regulations were not implemented until after 1979.

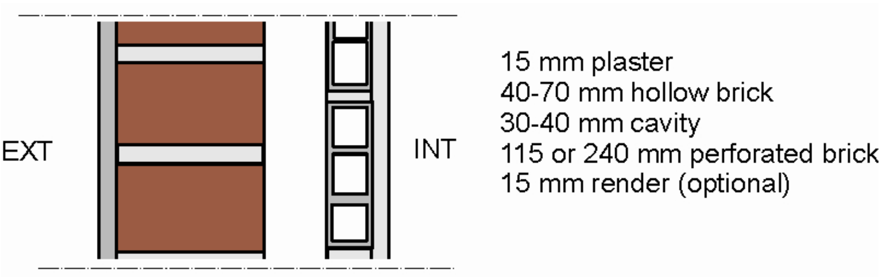


Figure 8. Figure Non loadbearing cavity brick wall without insulation.

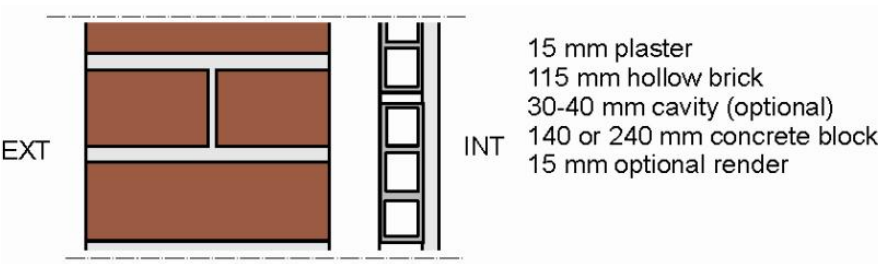


Figure 9. Non loadbearing concrete block wall without insulation.

Refurbishment technologies

Refurbishment implies that changes are made to the wall construction, and normally includes adding new insulation. Thus maintenance or minor repairs are not classified as refurbishment. Emphasizing the role of the insulation layer with regard to the moisture and temperature balance of the wall, the place where the new (insulation) layers are added is here used as a primary criterion for classification.

- Technologies for replacing existing walls.
- Technologies for applying external (insulation) layers.
- Technologies for inserting (insulation) materials in cavities in existing walls.

- Technologies for applying internal insulation.
- Other refurbishment technologies.

Descriptions and examples of these classes are given below.

Technologies for replacing existing walls

External walls can be replaced, particularly when they are not a part of the bearing system of the building. This could typically be the case in curtain walls of high-rise buildings, or parts of walls in residential blocks of flats. These walls can then be replaced totally, with a large freedom in selecting the new wall type. Such a procedure makes it possible to access large parts of the building with a building crane, which could be beneficial in cases where large parts of the building are remodelled. In principle it may also be possible to replace load-bearing walls completely, but this is generally not an economical solution, and is only selected in very special cases, e.g. when decay necessitates reinforcement of weakened structures. It is more usual that the non-load bearing layer(s) are replaced leaving the load bearing part as it is.

Technologies for applying external layers

External insulation (see the next figure) is normally the preferred method for adding insulation to existing buildings, as this method minimizes the loss of interior space, it is often possible to perform while the building is in use, and it makes it possible to avoid thermal bridges and moisture problems in a good way. Normally the added materials (insulation, vapour barriers, cladding materials etc.) are fixed to the load carrying system of the existing walls, but in some applications, new materials, typically brick veneers are built from the foundations. Some degree of removal of external construction, e.g. external siding, may be included in this case.

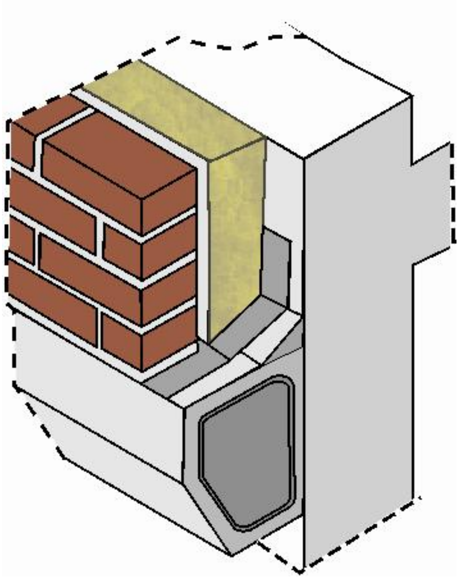


Figure 10. Example of external insulation with brick veneer resting on console fixed to foundations. BKS 723.312.

Technologies for inserting materials in cavities in existing walls

Walls with cavities can often improve their thermal properties if materials are inserted in these cavities. Blowing of insulating fibres or foams are the most common, but it may also be possible to remove internal or external surface materials and apply insulation or sheeting materials. In some cases older materials (sawdust, clay, etc.) are removed by vacuuming before blowing in new insulation materials.

Technologies for applying internal insulation

While generally inferior to external insulation, aesthetical, practical or other reasons sometimes makes it desirable to apply insulation inside of the existing construction. The new parts of the construction are fixed to the carrying system of the existing external wall, internal bearing walls or to floor dividers. The main typical problems are the discontinuity of the insulation layer because of partition walls and intermediate floors and the risk for condensation.

Other refurbishment technologies

Technologies where new materials are not applied to any great extent may still change the properties of the wall. Examples include application of “hot” or “cold” or controllable surface coatings to change heat absorption, water repellents, electric currents or other waterproofing measures to reduce the moisture content of the walls, or ventilation of wall cavities to reduce moisture problems or recover heat.

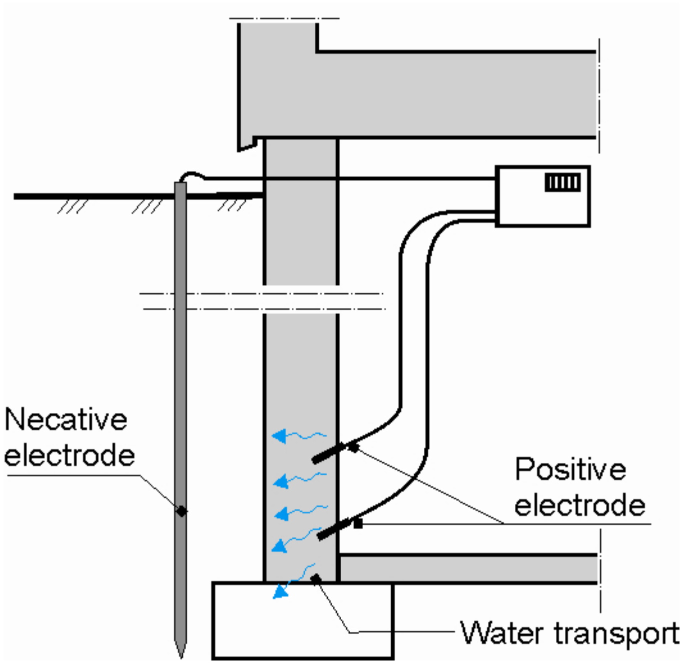


Figure 11. Electro-osmotic removal of moisture in a foundation wall. BKS 727.121.

Current refurbishment methods used in Europe

There are many refurbishment methods which are currently used for repairing external walls. Some of these refurbishment method alternatives are: repair of the exterior envelope, improvement of thermal insulation and air tightness, repair of structures and improvement of the facade cavity function.

The alternatives for the repairs of exterior envelope are:

- Repairing to correspond the original
- Replacing the old material with a new material
- Covering the old facade with another layer of material.

The alternatives for the improvement of thermal insulation are:

- Additional thermal insulation on the outside of facade
- Additional thermal insulation on the inside of facade
- Upgrading to a better thermal insulation.

The alternatives for the improvement of air tightness are:

- Repairing the structures' vapour barrier gaps (joints, penetrations etc.)
- Improving wind protection from the outside of the building
- Sealing the windows and wall structure interfaces.

Next section describes different refurbishment methods more specifically from the view point of Spain, the UK, Finland and Estonia.

In the Estonian building stock, heat-insulating plaster with 100 mm polystyrene or mineral wool is the most popular refurbishment method which is used in all of the following building types: large panel buildings, brick wall buildings and big block buildings. Cement chip board with stone rubble finishing and insulation between a wooden or metal frame is also used in large panel buildings and brick wall buildings. Heat-insulating plaster with 100 mm polystyrene or mineral wool encompasses about half of all refurbishment cases in large panel buildings and brick wall buildings, while the proportion for big block buildings is ~90%.

In Spain the most common facade refurbishment the, is the refurbishment of cavity wall buildings. Cavity wall buildings account for at least 70% of the refurbishment work. These are mostly made from reinforced concrete and the façade is composed of an inner brick layer, cavity and outer brick leaf with plaster or ceramic cladding. Facade cracks, interior mould or detachment of parts from the facade are the most common causes of refurbishment. Cavity filling and repairing just the outer leaf is the most common and cheapest technique. It is a cheaper alternative to exterior insulation or a ventilated facade. Insulated plaster (plaster with additives) is also used in about 3% of the facade refurbishment works.

In Finland and when dealing with concrete facades and external walls, the refurbishment method must be chosen considering the extent of the corrosion of reinforcement and the frost damage of concrete. In the case of severe damages, those are renovated with re-cladding methods. Examples of easier methods for concrete facades and external walls are as follows: mortar patching by hand, syringe concreting, concrete casting, painting, impregnation and electrochemical treatments.

Mortar patch methods are used when corrosion and erosion of the frost damage are mild. Surface treatments complement mortar patches. These general surface treatment methods are paintings and protective treatments. The facade paints must be water vapour permeable and they must have sufficient surface strength. Paint products are selected according to the concrete structure humidity conditions, because some paints are more vapour compact than others. The purpose of the protective treatments is to reduce the corrosion of steel and frost damages in concrete. Syringe-concreting and concrete-casting are basically mortar patch methods. They are normally used for repairing larger areas of damage, for example in load bearing and massive wall structures.

There are two options when choosing how to execute the renovation of brick facades. These options are to add a new brick layer onto the old external wall or tear down the old external wall envelope and replace it with a new envelope. Additional insulation is recommended in both renovation methods. Between the additional insulation and the outer wall there must be a 25–30 mm cavity. In the cavity, special attention must be paid to the removing of water from the window and door areas as well as from the plinth. In the case of wooden façades, the most important means of reducing weather corrosion and preventing biological damage is structural wood protection. This means that the wood humidity level must be kept low so that suitable living conditions for dry rot is not encouraged. At the same time humidity must be also kept steady, so that the development of cracking is reduced. By protecting wooden façade surfaces from rainwater and sunlight, the material durability can be extended. The impact from sunlight and rainwater can be reduced to some extent, with chemical wood protection, in other words, by painting. However, chemical wood protection alone is not enough, if structural solutions are poor. If the cladding has initially been non-ventilated, it is good to leave approximately 25 mm cavity behind a new cladding when the modification work is made. In addition, the new timber cladding must be at least 21 mm thick. Sufficient plinth height (approx. 300 mm) must also be taken care of during the repair work.

In the UK, solid masonry walls are usually thermally upgraded with the addition of insulation to either the inner or outer face of the wall. The use of external insulation may be restricted if the external finish is of stone or brick and these are required to be retained. In addition, the application of internal insulation may be restricted if there are space limitations within the building or if there are historical finishes which need to be retained. In some applications a combined approach, in other words both external and internal, insulation may provide a practical solution to thermally upgrading solid masonry walls. However, it is advisable that the multi-layers of insulation behaviour are fully assessed because of the possibility of condensation in the structure. The application of internal insulation generally requires removal of tenants/residents during the refurbishment work, whereas the external insulation may prove a simpler, more cost effective solution. However, all these factors should be considered when assessing the barriers to improving external facade performance.

<u>Climatic conditions</u>

The climatic variables which have a direct impact on heat exchange between buildings and their surroundings are:

- external air temperature–influences heat exchange at external surfaces via convection and heat exchange through the direct replacement of internal air with incoming external air;
- wind speed and direction–influences the convective coefficient at the external surface of the building as well as the air pressures on different facades which govern the rate of infiltration in the building;

- solar radiation–determines heat gains through windows and openings in the external façade, and to a lesser extent through the opaque fabric; and
- longwave radiation–governs the radiative exchange between the external surface of a building and its surroundings.

Other features of the climate may influence heat exchange between buildings and their surroundings. Precipitation, for example, can alter the hygrothermal properties of building materials such that encourage greater heat exchange between the building and the external and internal environments. The likely impact of precipitation will in part be influenced by the altitude and degree of exposure of the building facades. All buildings are exposed to a microclimate shaped by the topography, surrounding vegetation and other buildings.

Köppen-Geiger zones for Europe

The number of relevant zones reduces as the scope of the map is reduced. The climate in Europe is mainly temperate or cold, with small pockets of more extreme climate in mountainous and exposed northerly areas. There are some areas classed as polar, but these tend to be where few people are living and so can be expected to produce few carbon dioxide emissions. Köppen climatic zones for Europe are presented in (Peel et al. 2007).

Precipitation

Although the data used to define Köppen-Geiger zones includes precipitation, it is worth considering this separately because in some cases precipitation can have a major impact on the thermal performance of building materials and on the quality of the internal environment in buildings. Figure 12 shows the average annual precipitation in Europe.

There are high concentrations along western coasts north of Lisbon and in the alpine region. Most of the precipitation in the Alps falls as snow, though there may be pockets of high rainfall on the southern flanks of the mountains. The high levels of precipitation along the western seaboard are attributable to rainfall which is driven by the moisture-laden prevailing winds off the Atlantic Ocean.

Figure 13 shows changes in precipitation as predicted by four different climate change models. Although there are important differences in the predictions there is general agreement that precipitation levels will increase in most northern parts of Europe. There is less agreement about how much this is likely to increase, but it is probably safe to assume that rain, hail and snow will remain features of many climatic zones in Europe.

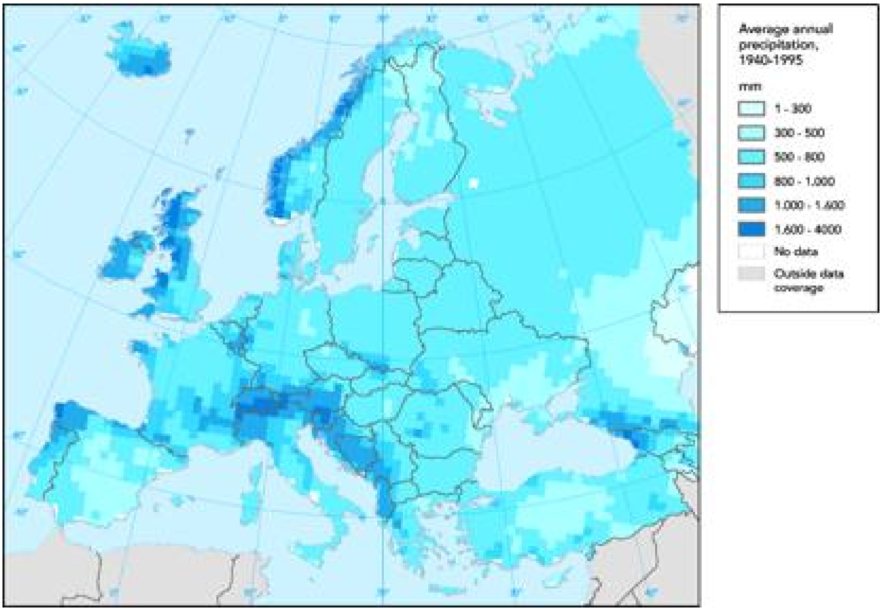


Figure 12. Average annual precipitation in Europe. Source: European Environment Agency. Available at http://www.eea.europa.eu/data-and-maps/figures/average-annual-precipitation (2011).

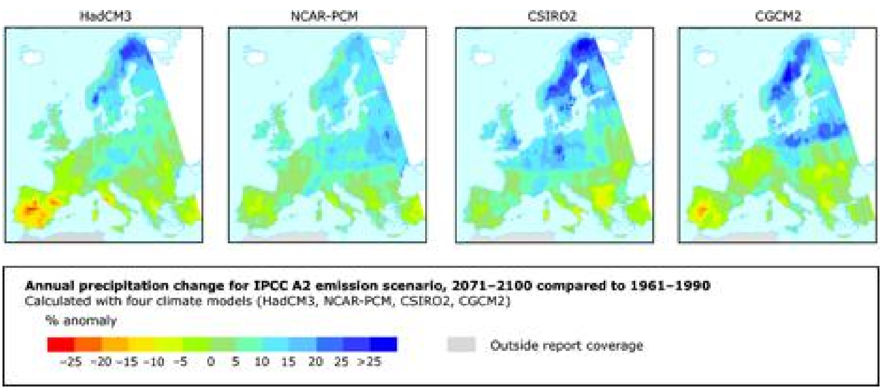


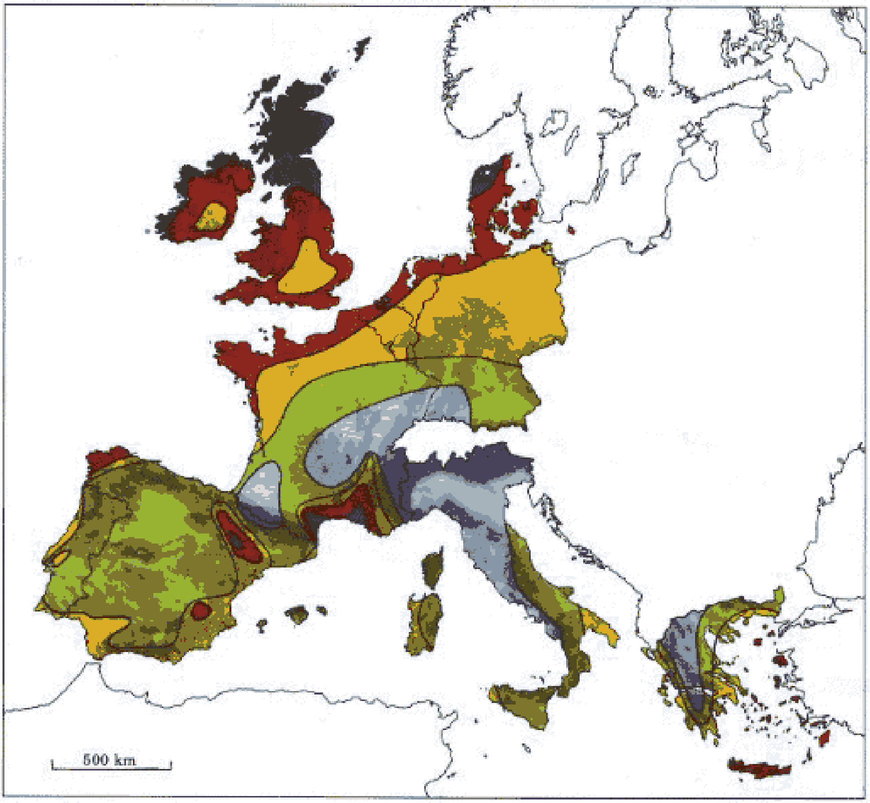
Figure 13. Predicted changes in annual precipitation from four different models. Source: European Environment Agency. Available from http://tinyurl.com/24r2mzy (2011).

Normally, precipitation poses few problems for existing buildings, except for extreme weather events that lead to flooding. The main concern is the extent to which precipitation alters the properties of facade materials and constructions, and this is usually only when it is combined with other climatic features, such as wind.

Wind

Wind impacts on the thermal performance of facades by determining the convective coefficient at the external surfaces and the rate of evaporative cooling from wet surfaces and materials. It also influences the rate of air infiltration as well as the ventilation rates. However, in some cases the main issue is wind-driven rain, which can penetrate the outer leaf of external wall and roof constructions.

Figure 14 shows the annual average wind speeds across Europe as extracted from the European Wind Atlas. The Atlas views wind as a resource for generating energy, but it also serves as a useful indicator of the wind environment across Europe.



Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 14. Average annual wind speeds in Europe. Source: European Wind Atlas, available at www.windatlas.dk/Europe/About.html (2011).

It may be useful to know the frequency of gusts for specific locations and closer to the ground, where they could have the greatest influence on the external walls, but this information is not available.

<u>Solar radiation</u>

The impact of solar radiation on the external walls of buildings depends heavily on the orientation of the wall as well as the available solar energy at given latitude.

However, solar radiation since is the most dependent on local conditions, principally obstructions by surrounding objects and also cloud cover.

Degree days

For building physicists and others with an interest in the energy required to condition interior spaces, the degree day concept is important. Degree days provide an indication of severity of the climate in different locations by documenting when during a given year the external air temperature falls below a specified (base) temperature thus requiring a building to be heated or rises above a base temperature, indicating the need for cooling. The calculation of heating degree days (HDD) and cooling degree days (CDD) historically is based on measured temperatures in different locations and normally uses a base temperature of either 18 °C or 15.5 °C. The calculation takes into account how far the external air temperature deviates from the base. Degree days are most commonly used to convey the relative severity of the climate in different geographical regions. Table 5 shows heating degree days for different countries in the period 2000–2004.

Table 5. Table Annual heating degree days for selected countries.

Year	Estonia	Spain	Italy	Finland	Sweden	United Kingdom
2000	3906	1814	1959	5215	4932	3247
2001	4345	1750	1833	5741	5394	3369
2002	4271	1629	1820	5706	5180	3141
2003	4421	1770	1971	5658	5227	3084

Proposed climatic zones for SUSREF

When deciding the adequate number of climatic zones for European assessment of refurbishment concepts, it is worth considering the population density across Europe as a way of deciding how many people are subjected to the different conditions.

As the next figure suggests, the climate of Europe has two main axes dictated by proximity to the influence of the Atlantic Ocean (and the Gulf Stream) and by the access to solar radiation largely dictated by latitude. These axes are evident in the Köppen-Geiger scheme for Europe.

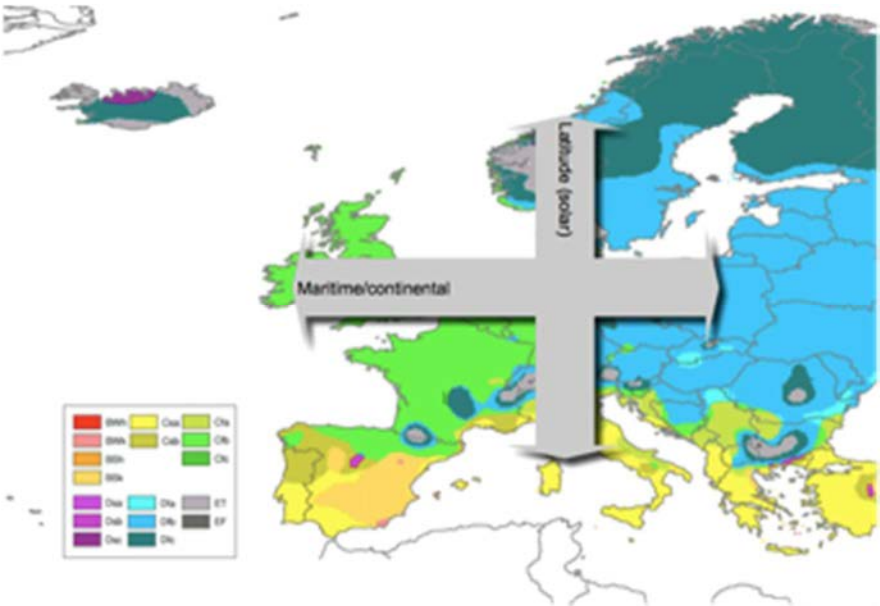


Figure 15. Main dimensions of climate in Europe (original source Köppen climatic zones for Europe. (Peel et al. 2007)

For the SUSREF project, it should be sufficient to work with the four largest zones offered by the Köppen-Geiger scheme. These cover the main population centres and should also be applicable to buildings outside Europe, for example, in Russia and the former Eastern Bloc countries. The next figure shows the proposed climatic zones.

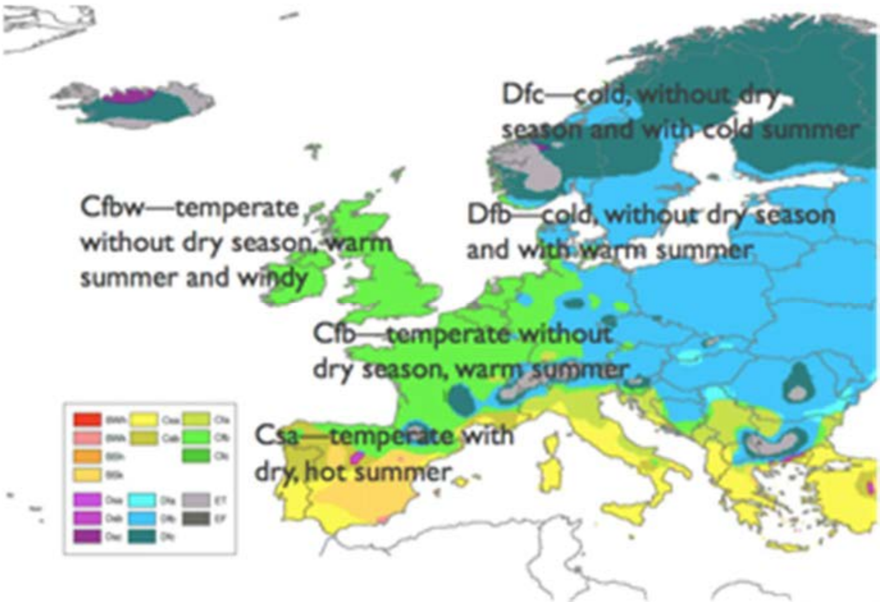


Figure 16. Proposed broad climatic classifications for SUSREF.

The proposed climatic zones for SUSREF are:

- Cfb–temperate without dry season, warm summer
- Cfbw–temperate without dry season, warm summer and windy
- Csa–temperate with dry, hot summer
- Dfb–cold, without dry season and with warm summer; and
- Dfc–cold, without dry season and with cold summer.

The main change is the addition of a further sub-level indicated by the “w” suffix to the existing Cfb category. This extra category takes into account the possibility of great influence of wind-driven rain on the performance of existing facades and the need, therefore, to address this within SUSREF. It should be noted, however, that the number of properties subjected to this climate is likely to be small.

<u>The influence of microclimate</u>

Topographical and other physical features of the immediate context can have a significant impact on the actual microclimate which surrounds a building, but it is difficult to address these in a climate classification system. However, it will be important to remember such influences when specific cases for refurbishment are considered. The key question to ask is: are the differences in microclimates enough to render some solutions impractical or inappropriate. Perhaps there is a need to develop a sub-classification scheme within the overall regional classification.

The presence of vegetation in the immediate vicinity of a building can have a significant influence on the hygrothermal performance of the façade. In addition to the obvious shading and sheltering provided by trees and shrubs, there can be influence on the microclimate through transevaporation, leading to cooling effect. However, it is not possible to make generalisations about the possible impacts since these will vary from one location to another. It will be important when deciding which buildings to study in the field that they are not subject to influence from local vegetation.

Urban heat islands are built-up areas where the average temperature is significantly higher than in the surrounding areas, for example in compact cities with adjacent countryside. The increase in temperature is mainly the result of heat produced by urban activities–traffic, long-wave radiation from buildings–and reduced exposure to the extremes of climate because of the shelter provided by other buildings and infrastructure.

Classification of indoor environment

The main objective for erecting buildings is generally to maintain a suitable protection from outdoor conditions, and make the indoor environment within the buildings suitable for their use. Thus any changes to building components should take into account how the changes will affect the indoor environment. At the same time, the indoor environment will affect the heat and moisture balance of the building components. The two aspects are considered separately.

Indoor environment is a broad term that could be defined as all extrinsic factors affecting people inside buildings. Indoor climate is normally defined as the physically measurable subset of these factors, and is often divided into thermal, chemical, actinical, acoustical and mechanical climate, excluding the psycho-social and aesthetical factors of the indoor environment. The next table define aspects of indoor environment.

Table 6. Groups of indoor environment factors illustrated with examples of problems and possible effects.

Group	**Factors**	**Typical problems (examples)**	**Possible outcomes (examples)**
Thermal environment	Air temperature Radiation temperature Air movement Air humidity	Summer overheating Sun radiation through windows Draft from leaky windows Very dry air in cold periods	Discomfort Production loss Accidents
Acoustic environment	Sound pressure, resonance, ultrasonic vibrations.	Traffic noise Ventilation noise	Annoyance Stress Increased blood pressure Disturbed sleep
Actinic environment	Light and ionizing radiation	Glare from windows, insufficient light Radon from ground	Production loss, tiredness, lung cancer
Chemical environment	Composition of air (gases, droplets and particles Other exposition to chemicals from the building, e.g. contact with building surfaces.	Particles from indoor combustion, Microbes from moisture damage Isocyanides from (application of) building products	Discomfort, stuffy nose, tiredness, production loss, asthma.
Mechanical environment	Physical shape of building and furnishing	Steps, edges, space	Accidents, reduced accessibility
Psycho-social environment	Workload, social interactions, etc.	Lack of control of work situation, fear of harmful environment	Increased sensitivity to other agents.
Aesthetic environment	Design, colors, appearance	Unappealing surfaces due to wear and tear	

The quality of the indoor environment has a profound effect on human health, wellbeing and ability to function. The World Health Organization (WHO 2007, WHO 2002) estimates that 1.5 million deaths and 2.7% of the burden of disease globally can be attributed to indoor air quality, the main part of this due to unvented combustion of solid fuels for cooking and room heating. In most European countries such combustion is of no or small importance, even if 300 yearly deaths and yearly loss of 4600 disability adjusted living years (DALYs) was estimated for Romania (WHO 2007). Radon is an important risk factor for lung cancer, and high indoor air concentration in countries like the Czech Republic, Finland, Luxembourg, Sweden, Norway and deaths attributable to radon exposure in indoor environments is in the order of hundreds or thousands in most European countries.

For many other indoor environmental factors and possible consequences, the link between exposure and outcome is complicated, and the scientific basis for guidance, classification and legislation is often limited. Particularly challenging is the identification of causative agents for the development of asthma and hypersensitivity. Asthma prevalence is increasing very fast in industrial countries, and indoor environmental exposure is strongly suspected to be of prime importance, yet which such exposures that are of importance and what characterizes susceptible individuals are largely unknown (Eder & al. 2006). Speculations of possible links between indoor exposures and development of disorders like diabetes, autistic spectrum disorder or attention deficit hyperactivity disorders have been raised, but remain speculative.

Relevant regulation at the European Community level

The Construction Product Regulation requires that the construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of their workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate, during their construction, use and demolition, in particular as a result of any of the following:

(a) the giving-off of toxic gas;
(b) the emissions of dangerous substances, volatile organic compounds (VOC), greenhouse gases or dangerous particles into indoor or outdoor air;
(c) the emission of dangerous radiation;
(d) the release of dangerous substances into ground water, marine waters, surface waters or soil;
(e) the release of dangerous substances into drinking water or substances which have an otherwise negative impact on drinking water;
(f) faulty discharge of waste water, emission of flue gases or faulty disposal of solid or liquid waste;
(g) dampness in parts of the construction works or on surfaces within the construction works.

Relevant standards and a proposal for classification

Important principles for classification of indoor climate are given in EN 15251 (2007) "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics".

The standard defines four classes for indoor environment. Class II is described as meeting normal expectation level, suitable for new and refurbished meetings. Class I is a level suitable for users with special demands, while Class III is an acceptable level that can be applied for existing buildings. Class IV is defined as buildings not meeting the requirements for the classes mentioned above.

Radon concentration, microbial and moisture problems are not treated in the standard.

Also other important factors for indoor environment are connected to the refurbishment process. Dusts, noise, emissions from chemical building products are examples of such factors.

The following table classifies indoor environmental factors as good, normal or bad. For the factors treated in EN 15251 class I corresponds to good, class II normal and class III and IV as bad. Criteria for thermal environment, ventilation/air quality, dampness and mould, noise and radon are given. Guidance on methods and interpretation of user satisfaction is given.

Table 7. Suggested criteria for classification of indoor environment parameters. National regulations may apply.

Factor	Good	Moderate	Bad	Reference
Thermal environment	According to Class 1 or PPD < 6%	According to class 2 or PPD < 10%	Not meeting criteria of class 2. PPD > 10%	EN 15251 Annex A
Air Quality				
Ventilation	More than 0.7 air changes per hour of clean supply air without thermal comfort problems. Supply air to living room and all bedrooms.	More than 0.6 air changes per hour of clean supply air without thermal comfort problems.	Not meeting requirements for moderate	EN 15251, Annex B
Pollution sources – materials	Low- polluting materials, conforming with M1 or Danish Indoor Environment label.	Normal materials, no documentation	Materials with identified problems, see table 4 for examples, exposed to indoor air, or containing substances on Candidate list.	
Dampness and mold	No detectable mold damage	Occasional condensation occurs. Minor areas of organic growth not exposed to indoor air of rooms for longer	Regular condensation, organic materials exposed to RH > 80% for extensive periods, visible	WHO 2009

Factor	Good	Moderate	Bad	Reference
		occupancy.	mold growth exposed (directly indirectly to occupied spaces)	
NO_2	0.08 mg/m³ (24 h avg)	0.2 mg/m³ (1 h avg)	Not meeting other criteria	WHO 2005, Scanvac 1990
CO	6 mg/m³ (8 h avg)	6 mg/m³ (8 h avg)	Not meeting other criteria	Scanvac 1990
Ozone	< 0.05 mg/m³ (8 h avg)	< 0.1 mg/m³ (8 h avg)	Not meeting other criteria	WHO 2005, Scanvac 1990
Particles ($PM_{2,5}$)		25 µg/m³ 24-hour mean	Not meeting other criteria	WHO 2005,
Noise				
From outside: $L_{p,A,eq24h}$ (dB)	25	30	35	NS 8175, class B, C or D
From technical equipment. $L_{p,A,eqT}$ (dB) $L_{p,A,Fmax}$ (dB)	25 27	30 32	35 37	NS 8175, class B, C or D
Radiation				
Radon	< 100 Bq/m³ yearly avg.	100–200/m³ Bq yearly avg.	> 200 Bq /m³ yearly avg.	WHO 2009

Indoor climate as environment for construction and installations

In most buildings the only factor in indoor climate with possible detrimental effect is moisture. The moisture in indoor air could be described in terms of relative moisture or absolute moisture, but has little meaning without description of temperature. Measures like dew point, absolute moisture content or difference in absolute moisture between inside and outside is often more interesting.

As the renovation process may involve changing the ventilation, the most valuable descriptor would generally be “moisture production”, from which the other variables may be reconstructed if outdoor climate and material properties (buffering effect) is known. This parameter can, however, not be measured directly in the field, and data are scarce.

ASHRAE Standard 160 (ASHRAE 2009) gives design moisture generation rates. EN ISO 13788 (2001), Annex A gives moisture loads for use in calculation of surface temperatures to avoid risk of condensation (CEN 2001). The model predicts internal RH by type of building, moisture class, outdoor vapour pressure and outdoor temperature. The model is intended for steady-state assessment of interstitial condensation using the Glaser method. EN 15026 (2007) on the other hand describes numerical assessment of transient moisture transfer. This standard describes classes for high and low occupancy office buildings or dwellings.

As for indoor temperatures, user preferences and habits vary, affecting the way the users interact with the building and its technical systems. For building simulations it is often supposed that the indoor temperature will be kept somewhere between 20 °C and 25 °C (EN 15026) or in a narrower band (ASHRAE Standard 160), but some users may prefer higher or lower temperature than this, either for comfort or for trying to save energy. Thus, relative humidity may vary considerably between rooms in a single dwelling.

3 Systematic approach for the sustainability assessment of refurbishment concepts of exterior walls

This Chapter introduces the sustainability assessment concept develop by SUSREF project. In addition, this Chapter presents and gives guidelines about the use of different relevant assessment methods. These include energy assessment methods, building physical assessment methods and life cycle assessment methods.

3.1 Introduction

This chapter presents a framework for the sustainability assessment. The framework includes the outline for the sustainability assessment, description of assessment methods and the initial basic data for calculations. The basic data consists of environmental data for energy and relevant building materials.

The sustainability of the developed refurbishment concepts (presented in Part B of the publication) was assessed considering the following aspects:

- building performance
- durability
- environmental impacts and
- life-cycle costs.

The starting point is that achieving and maintaining the desired building performance while minimising the negative impacts in terms of environmental and economic impacts are all essential elements of sustainable building. Though environmental impacts and LC costs indicate aspects of sustainability, the quantifying and comparing cannot be done without a common reference. When comparing different concepts and design options, performance aspects are the underlying factor.

3.2 Framework for the assessment of sustainable performance of refurbishment concepts

3.2.1 Introduction

Sustainable development of buildings and other construction works brings about the required performance and functionality with minimum adverse environmental impact, while encouraging improvements in economic and social (and cultural) aspects at local, regional and global levels (ISO 15392, 2008). Sustainable building process is defined as the overall quality of the process that enables the delivery of sustainable buildings. The three main prerequisites for sustainable building are 1) the availability of sustainable building technologies, 2) the availability of methods and knowledge for sustainable target setting, design, procurement, monitoring and management of buildings, 3) the development of sustainable building processes and the adoption the new sustainable building technologies, methods and working models.

ISO 21929 (2011) defines aspects of sustainable building as follows:

Table 8. Framework: Core areas of protection, aspects of building that impact on these areas of protection and indicators that represent these aspects. The number of X.s indicates the primary areas to which the aspects have a potential impact – XX indicates primary (or direct) influence and X secondary (or indirect) influence.

Aspect		CORE INDICATORS	CORE AREAS OF PROTECTION						
			Ecosystem	Natural resources	Health and well-being	Social equity	Cultural heritage	Economic prosperity	Economic capital
1	Emissions to air	Global warming potential	XX		X	X		X	
		Ozone depletion potential	XX		XX			X	
2	Use of non-renewable resources	Amount of non-renewable resources consumption by type		XX				X	
3	Fresh water consumption	Amount of fresh water consumption	XX	XX		X		X	
4	Waste generation	Amount of waste generation by type	X	XX	X				
5	Change of land use	Indicator measures the changes in land use caused by the development of the built environment with help of a list of criteria	XX	XX			X		
6	Access to services	Indicator measures the access to services by type with help of criteria	XX		X	XX			XX
7	Accessibility	Indicator measures the accessibility of building and its curtilage with help of a list of criteria				XX			
8	Indoor conditions and air quality	A set of indicators that measure the air quality and sub-aspects of indoor conditions with help of a list of measurable parameters			XX			X	

Aspect		CORE INDICATORS	CORE AREAS OF PROTECTION						
			Ecosystem	Natural resources	Health and well-being	Social equity	Cultural heritage	Economic prosperity	Economic capital
9	Adaptability	Indicator measures the flexibility, convertibility and adaptability to climate change with help of a list of criteria		XX	X				XX
10	Costs	Life cycle costs						X	XX
11	Maintainability	Indicator measures the maintainability against the results of service life assessment and with help of a list of criteria or with help of expert judgement		X			X		XX
12	Safety	Indicator measures the sub-aspects of safety against the results of simulations or fulfilment of the safety related building regulations			XX				X
13	Serviceability	Indicator measures serviceability with help of a list of criteria or with help of post-occupancy evaluation						XX	
14	Aesthetic quality	Indicator measures the aesthetic quality against the fulfilment of local requirements or with help of a stakeholder judgement					XX		

3.2.2 Assessment criteria

The following list shows the sustainability assessment criteria defined by the SUSREF project. For sustainability of the developed concepts and technological solutions will be assessed considering the following aspects:

ASSESSMENT CRITERIA FOR REFURBISHMENT CONCEPTS OF EXTERIOR WALLS

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 following table describes the basic assessment approaches for criteria.

Table 9. Assessment methods for different sustainability criteria and their use in SUSREF for the assessment of refurbishment concepts (see Final report, Part B and Part C).

Durability and service life
Durability will be mainly assessed on the bases of building physical behaviour and risks for deterioration because of moisture related problems. Corrosion and mould growth will be analysed with help of building physical simulation. Different simulation tools will be used: – For constructions and solutions consisting of just homogenous layers, 1D heat and moisture calculations tools (e.g. WUFI-Pro, Match). Ventilated cavities can be studied simplified with these tools, too. – For constructions containing inhomogeneous layers, e.g. fastenings, and ventilation cavities, 2D heat and moisture calculations tools (e.g. WUFI2D, DELPHIN) should be used. 3D effects must be taken into account by qualified modification of the model, together with a possible 3D thermal calculation. – Generally, 1D tools are sufficient for most of the analysis with skilled expert use. The computation in 2D is usually time-consuming and the detailed information from a 2 or 3D calculation may be overruled by other uncertainties. – For qualitative assessment also 2D heat transmission tools can be used for

optimisation of the thermal bridges and assessment of the critical temperatures for e.g. mould risk (HEAT2, THERM)

- The risk for mould growth is also assessed with help of mould growth modelling.

The assessment can also make use of methods and tools developed earlier for service life estimation. These tools include the ENNUS tools developed at VTT. ENNUS®-tools has been developed for the service life assessment of building structures in compliance with ISO 15686-1. The tools help designers to determine parameters that affect the service life of the structure under scrutiny. The considered parameters include materials quality, structural design, work execution, outdoor and indoor conditions, use conditions, and care and maintenance level. The method is known as the factor method, and service life is obtained by multiplying the reference service life by these factors.

VTT has developed ENNUS® tools[3] for concrete outdoor walls and balconies, steel facades and roofings and for wooden outdoor walls.

Impact on energy demand for heating and Impact on energy demand for cooling

The impact on energy demand for heating will be assessed on the bases of target U-values and on the bases of whole building energy consumption calculations.

Simple building energy calculations are based on calculating the heat losses and gains and the resulting energy need. Building energy simulations, in addition, take account the dynamic effects of e.g. thermal mass of the building and may lead to less energy need than the simple calculation. The alternative solutions will be simulated by means of simulation tools, such as EnergyPlus or TRNSYS. Some cases will be analysed in different climates with help of whole building hygrothermal models (e.g. WUFI+ or IDA ICE).

Impact on renewable energy use potential (use of solar panels etc.)

Impact on renewable energy use potential (for example the use of solar panels) will be assessed as expert assessments.

Environmental impact of manufacture and maintenance

The environmental impact from manufacture and maintenance will be assessed on the basis of LCA.

Impact on daylight

Impact on daylight will be assessed as expert assessments.

Indoor air quality and acoustics

The indoor environment parameters are outlined as follows: 1) Thermal environment 2) Air Quality (Ventilation, Pollution sources – materials, Dampness and mold, NO_2, CO, Ozone, Particles ($PM_{2,5}$) 3) Noise from outside and from technical equipment 4) Radiation (Radon).

Indoor environmental factors are classified as good, normal or bad. EN 15251 class I corresponds to good, class II normal and class III and IV as bad. Criteria for thermal environment, ventilation/air quality, dampness and mould, noise and radon are given. Guidance on methods and interpretation of user satisfaction is given. No indoor

3 http://virtual.vtt.fi/virtual/environ/ennus_e.html

environment tests will be carried out. The effect of alternative refurbishment concepts on the reduction of risk for moisture related problems like corrosion and mould growth and thus for impaired air quality will be assessed with help of building physical simulations. The acoustical quality will be assessed in terms of air sound insulation factor (R'w, dB between building spaces). However, this research will not make sound insulation testing.
Structural stability and Fire safety
The structural stability and fire safety of the alternative refurbishment concepts will be assessed against relevant standards and regulations. However, this research will not carry out mechanical or fire testing of the concepts.
Aesthetic quality
The aesthetic quality and the effect on cultural heritage of the alternatives will be assessed with help of architecture panels. These panels will be invited to assess, discuss and present improvement possibilities for the selected number of alternative refurbishment concepts.
Effect on cultural heritage
The effect on cultural heritage of the alternatives will be assessed with help of architecture panels. These panels will be invited to assess, discuss and present improvement possibilities for the selected number of alternative refurbishment concepts. The target of these panels will be to identify the key criteria with regard to the effects on cultural heritage.
Life cycle costs
Life cycle costs will be assessed by using the LCC method.
Need for care and maintenance
The need for care and maintenance will be assessed and explained with help of expert knowledge concerning the service life behaviour of product in different outdoor and indoor conditions and typical use conditions. The measures which will be considered include issues like – needs for periodic inspections and surveys in order to avoid progress of initial deterioration – paintings, coatings and other surface treatments – renewals of components – necessary and laborious cleaning.
Buildability
Buildability will be assessed as expert assessment.
Disturbance to the tenants and to the site
Disturbance to the tenants and to the site will be assessed as expert assessment.

The following Table summarises the principal criteria with regard to the type of the assessment method, measured aspect and unit.

Table 10. Characterisation of the assessment methods.

Assessment criteria	Assessment method	Measured main aspect	Unit
Durability and service life	Calculation/Measurement	risk for deterioration	
Impact on energy demand for heating	Calculation/Measurement	heating energy consumption	kWh/a
Impact on energy demand for cooling	Calculation/Measurement	cooling energy consumption	kWh/a
Impact on renewable energy use potential	Calculation/Measurement	renewable energy production	kWh/a
Environmental impact of manufacture and maintenance	Calculation/Measurement	carbon footprint	CO2e
Impact on daylight	Calculation/Measurement	lighting level	lux
Indoor air quality and acoustics	Calculation/Measurement	indoor environment quality (EN 15251)	good, normal, defective
Need for care and maintenance	Calculation/Measurement	maintenance cost	€
Life cycle costs	Calculation/Measurement	life cycle cost	€
Structural stability	Calculation/Measurement		
Buildability	Expert assessment		
Aesthetic quality	Expert assessment		
Effect on cultural heritage	Expert assessment		
Fire safety	Expert assessment		
Disturbance to the tenants and to the site	Expert assessment		

3.3 Life cycle assessment

3.3.1 Introduction

The general principles on life cycle assessment (LCA) of products and services have been agreed upon and introduced with help of standardisation (ISO 14040 and ISO 14044). In addition, there are international standards available on the formats, contents and processes of environmental assessment and declarations of products (ISO 14020 and ISO 14025).

The life cycle of a product covers all the phases of the product life from the extraction of natural resources, through transportation, design, manufacture, distribution, assembly, use, maintenance and repair to their recycling or final disposal as waste. Life cycle assessment supports the management of environmental aspects of products and processes. LCA is a technique for assessing the environmental aspects and potential impacts with a product by (ISO 14040):

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave). The standard LCA phases are:

- Goal and scope definition: Definition of the main objective of the study, the Functional Unit, the system boundaries and the assumptions/limitations of the whole LCA study;
- Life Cycle Inventory (LCI): Collection of Inventory data considering raw materials consumption, energy consumption, air emissions, water emissions and solid waste linked to the production, use and end of life of the component under study;
- Life Cycle Impact Assessment: Environmental data-check and conversion of the inventory data into the main environmental impact categories (Global warming, Acidification, Eutrofication, Photochemical Smog formation and Eco-toxicity, etc.). ILCD Handbook, the European Guidance document provides the general framework and methodological requirements for impact assessment as also outline in general terms in ISO 14044.
- ILCD[4] promotes the availability, exchange and use of coherent, robust life cycle data, methods and studies for decision support in policy making and in business. The network is open to all data providers from business, national LCA projects, research groups, consultants, research projects, and others. The documentation and publication of LCI and LCIA data sets is supported by the related ILCD data set documentation and exchange format. A related data set editor allows the documentation, editing, and compliance-verification of ILCD data sets. The European Reference Life Cycle Database (ELCD) with European scope inventory data sets[5] provide LCI data from front-running EU-level business associations and other

4 Internationally coordinated and harmonized ILCD Handbook of technical guidance documents for LCA

5 Life Cycle website http://lct.jrc.ec.europa.eu/assessment/data

sources for key materials, energy carriers, transport, and waste management. Focus is on data quality, consistency, and applicability. The data sets are accessible free of charge and without access restrictions. The data sets of the ELCD database will contribute key European data to the international ILCD Data Network.

The ELCD database has the following structure. The numbers indicate the datasets included.

- End-of-life treatment (45)
- Energy carriers and technologies (173)
- Materials production (63)
  - Plastics (24)
  - Metals and semimetals (11)
  - Other mineral materials (6)
  - Organic chemicals
  - Inorganic chemicals
  - Water (6)
- Systems (14)
  - Packing (1)
  - Construction (13)
- Transport services (22).

With regard to the environmental assessment of exterior wall refurbishment concepts, the data given for the following systems may be useful:

- glass wool
- rock wool
- expandable polystyrene
- aerated concrete blocks
- calcium silicate blocks
- lightweight concrete blocks
- particle board
- pre-cast concrete.

ISO and CEN have developed building and construction related sustainability standards, which cover all levels and all sustainability aspects as follows:

	Environmental aspects	Economical aspects	Social aspects
Methodological bases	ISO/15392: General principles ISO/TR 21932: Terminology		
Buildings	ISO 21929-1: Sustainability Indicators – Part 1 - Framework for the development of indicators and a core set of indicators for buildings		
	ISO/21931-1: Framework for methods of assessment of the environmental performance of construction works		
Products	ISO/21930: Environmental declaration of building products		

Figure 17. Suite of related International Standards for sustainability in buildings and construction works.

Rules for the environmental declaration of building products are given in ISO 21930 (2007). According to ISO 21930 environmental information of an EPD, which covers all life-cycle stages ("cradle to grave") shall be subdivided into at least the four life-cycle stages:

- product stage (including information from raw material supply, transport, manufacturing of products and all upstream processes from cradle to gate);
- construction process stage (information from transport to the building site and building installation/construction);
- use stage/operation; use stage/maintenance (information on impacts from maintenance, repair, replacement and refurbishment, including all transport);
- end-of-life stage (information from deconstruction, reuse, demolition, recycling and disposal, including all transport).

According to the standard ISO 21930, Product Category Rules (PCR) are required when developing EPDs. The PCR give guidelines for the methodology used in the EPDs in the particular product category. A standard for PCRs has been developed also by CEN: EN 15804 "Sustainability of construction works – Environmental product declarations – core rules for the product category of construction products".

Table 11. The work programme of CEN/TC 350.

Framework level	EN 15643-1 (2010) Sustainability Assessment of Buildings – General Framework (TG)		
	EN 15643-2 (2011) Framework for Environmental Performance (TG)	EN 15643-3 (2012)Framework for Social Performance	EN 15643-4 (2012)Framework for Economic Performance
Building level	EN 15978 (2011) Assessment of Environmental Performance	prEN 16309 Assessment of Social Performance	Assessment of Economic Performance
Product level	EN 15804 (2012) Environmental Product Declarations		
	EN 15942 (2011) Communication Formats. Business-to-Business		
	CEN/TR 15941 Sustainability of construction works – Environmental product declarations – Methodology for selection and use of generic data		

3.3.2 Nationally recognised LCA methods for building products

When assessing the environmental performance of alternative refurbishment concepts, the use of European widely recognised data bases and especially the ELCD data base is recommended. However, because the included data is limited, it is also recommended to make use of nationally recognised environmental data for building products. Examples of these are as follows:

- RT Ympäristöselosteet – RT Environmental Declarations[6]
  The RT Environmental Declaration is based on the national methodology following the basic principles stated in the ISO standard series 14040 and 14020. The method considers also the preliminary results achieved within ISO CD 21930. It is developed in cooperation with the Confederation of Finnish Construction Industries RT, the Building Information Foundation RTS, VTT Technical Research Centre of Finland and companies in the

6 RT Environmental Declarations http://www.rts.fi/ymparistoseloste/index_RTED.htm

construction business. The RT Environmental Declaration is a voluntary and public document providing comparable and impartial information on the environmental impacts of building materials. It is a source of information for users, designers and constructors.

The data is available in http://www.rts.fi/ymparistoseloste/voimassaolevatympselosteet.htm

The method follows the basic principles of ISO 14040 and ISO 21930. The description of the method is available in www.rakennustieto.fi and its English version in http://virtual.vtt.fi/virtual/environ/ympsel_e.html (EKA method)

- Green Guide specifications [7]

  The Green Guide specifications are based on the BRE Global Environmental Profiles Scheme for Type III Environmental Product Declarations (EPD) for construction products. The methodology identifies significant environmental aspects associated with the Life Cycle Assessments (LCA) of construction products. Results from a certified Environmental Profile Scheme can be published and used by BREEAM or Code for Sustainable Homes assessors.

  Generic LCA for construction products and building systems provides a review of the environmental performances of a product or building system representative of UK industry. The results are published on the Green Guide to Specifications online: 1) Calculates common environmental profiles for manufacturers representing typical UK manufacturing practice, 2) Adds to existing online Green Guides specifications, 3) Beneficial to manufactures with unique processes or building systems. The results are generic for a product or building system, therefore, specific manufacturer claims cannot be made.

- epd-norge.no[8]

  The Norwegian EPD Foundation was established in 2002 by the Confederation of Norwegian Enterprise (NHO) and the Federation of Norwegian Building Industries (BNL). The reason for its establishment was an expressed desire from the Norwegian corporate sector relating to the development of credible, standardized and internationally valid Environmental Product Declarations for products and services. The Norwegian EPD Foundation's task is to verify EPDs in accordance with the international standard ISO 14025 – Environmental Declarations Type III. In order for an EPD to be valid pursuant to the ISO 14025 Standard it must be verified by a neutral third party. The goal of the Norwegian EPD Foundation is for Environmental Product Declarations to be the preferred communications tool when exchanging environmental information about

7 Green guide specifications http://www.bre.co.uk/page.jsp?id=1578

8 epd-norge.no http://www.epd-norge.no/article.php?articleID=1010&categoryID=188

products and services across all sectors both nationally and internationally. The Norwegian EPD Foundation collaborates with the leading international research institute SINTEF Building and Infrastructure, Ostfold Research Co. and the Norwegian University of Science and Technology (NTNU) among others on the development of Product Category Rules (PCR). To the extent that the Foundation has financial means available, it also supports the development of Product Category Rules (PCR). The Norwegian EPD Foundation is responsible for ensuring that Norwegian Product Category Rules (PCR) complies with the ISO 14025 Standard as well as ensuring that EPDs are developed in accordance with Product Category Rules – PCR. In each calculation case the data source is chosen so that it fits as well as possible for the case.

3.3.3 Environmental data for energy and materials

This section presents the basic principles that should be followed when selecting relevant environmental data. The section also gives some environmental profiles for materials and energy used in the assessment of alternative refurbishment concepts.

Fuels and electricity

Environmental impact for fossil fuel procurement (pre-combustion) is recommended to be based on ELCD data[9] when more relevant and spesific information is not available. All ELCD data for fuels represents cradle to gate inventory. The data set represents the region specific situation focusing on the main technologies, the region specific characteristics and import statistics.

The following Table shows the density and net calorific values for light fuel oil, heavy fuel oil, diesel oil, natural gas, and coal. The pre-combustion values for energies and raw-materials are presented in the following Table and emission factors presented in the Table following that.

9 http://lca.jrc.ec.europa.eu/lcainfohub/datasetCategories.vm?topCategory=Energy+carriers+and+technologies

Table 12. Densities and net calorific values for fuels.

	Light fuel oil	Heavy fuel oil	Diesel oil	Natural gas	Coal
Density (kg/dm^3)	0.84	0.98	0.84	0.000722	
LHV (MJ/kg)*	43	40	43	48	27

* LHV is a net calorific value, based on IPCC 2006 Guidelines Chapter 1[10] (IPCC 2006, (http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf).

Table 13. Non-renewable and renewable energy and raw materials for pre-combustion of fuels. Pre-combustion values based on the ELCD database.

	Non-renewable energy (MJ/kg)	Renewable energy (MJ/kg)	Non-renewable materials (kg/kg)	Renewable materials (kg/kg)
Light fuel oil	50.2	0.0671	0.165	-
Heavy fuel oil	44.2	0.0559	0.114	-
Diesel oil	50.4	0.0673	0.139	-
Natural Gas (desulphurised)	50.3	0.00331	0.118	-
Coal	27.7	0.0219	4.93	-

Table 14. Pre-combustion emission factors for fuels (calculated according to the ELCD data except for wood and peat).

	CO_2	CH_4	N_2O	CO_2e *	
Light fuel oil	7.00	0.0777	0.000162	9.0	g/MJ
Heavy fuel oil	6.73	0.0735	0.000156	8.6	g/MJ
Diesel oil	7.02	0.0781	0.000162	9.0	g/MJ
Natural Gas	5.95	0.1439	0.000114	9.6	g/MJ
Coal	3.93	0.294	0.000188	11.3	g/MJ
Peat	4.0	-	-	-	g/MJ
Wood	1.0	-	-	-	g/MJ

* CO_2e is a carbon dioxide equivalent. It is calculated according to emission coefficients CO_2 = 1, CH_4 = 25 and N_20 = 298 (IPCC WG1 report, July 2007, Chapter 2, page 212 table 2.14, http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/ar4-wg1-chapter2.pdf)

10 IPCC Guidelines, Chapter 1. 2006.

http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

Stationary combustion

Emission factors for stationary combustion in the category commercial buildings are based on IPCC Guidelines/Stationary combustion (IPCC 2006)[11]. Values are given on the basis of net calorific values. The emissions factors used for fuels for energy industry and residential category use are as follows (Table).

Table 15. Emission factors for stationary combustion in the category commercial buildings Values are given in net calorific value basis. Data is based on IPCC Guidelines/Stationary combustion (IPCC 2006).

	CO_2	CH_4	N_2O	CO_2e **	$CO2_{etot}$***
Fuel type	g/MJ	g/MJ	g/MJ	g/MJ	g/MJ
Default emission factors in the energy industries					
Light heating oil	74.1	0.003	0.0006	74,4	83,3
Heavy fuel oil	77.4	0.003	0.0006	77,7	86,3
Diesel oil	74.1	0.003	0.0006	74,4	83,4
Natural gas	56.1	0.001	0.0001	56,2	65,7
Bituminous coal	94.6	0.001	0.0015	95,1	106,4
Lignite coal	101	0.001	0.0015	101,5	112,8
Peat	106	0.001	0.0015	106,5	117,8
Wood or other solid biomass	0 *	0.030	0.004	1,9	2,9
Default emission factors in the residential categories					
Light heating oil	74.1	0.010	0.0006	74.5	83.5
Heavy fuel oil	77.4	0.010	0.0006	77.8	86.4
Diesel oil	74.1	0.010	0.0006	74.5	83.6
Natural gas	56.1	0.005	0.0001	56.3	65.8
Bituminous coal	94.6	0.010	0.0015	95.3	106.6
Lignite coal	101	0.010	0.0015	102	113
Peat	106	0.3	0.0014	113.9	
Wood or other solid biomass	0 *	0.300	0.004	8.7	9.7

* Biomass related CO_2 emissions are neglected because considering the initial binding of CO2 from the atmosphere during photosynthesis.
** Carbon dioxide equivalent
*** Total carbon dioxide equivalent including the pre-combustion value.

11 Guidelines for National Greenhouse Gas Inventories. Vol. 2. Energy. 2006. Chapter 2 Stationary combustion. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

IPCC all reports http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Mobile combustion

When accurate assessments are done for alternative refurbishment concepts, the transportation of products must also be taken into account.

LIPASTO data base[12] for traffic emissions will be made use of. The Unit emissions cover the amount of emissions emitted during operation of vehicles. Emissions are measured in mass units and allocated to each passenger or tonne of freight transported over one kilometre (g/tonne kilometre, g/passenger kilometre). Emissions and energy consumption per freight unit and kilometre are shown for the following four transport modes: Road traffic, railway traffic, waterborne traffic and air traffic.

In addition, the IPCC Guidelines Report Mobile combustion (IPCC 2006)[13] can also be made use of. Mobile sources produce direct greenhouse gas emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the combustion of various fuel types, as well as several other pollutants such as carbon monoxide (CO), Non-methane Volatile Organic Compounds (NMVOCs), sulphur dioxide (SO_2), particulate matter (PM) and oxides of nitrate (NO_x), which cause or contribute to local or regional air pollution. The IPCC report's mobile source category Road Transportation includes all types of light-duty vehicles such as automobiles and light trucks, and heavy-duty vehicles such as tractor trailers and buses, and on-road motorcycles. The following table gives the default values for motor gasoline, gas/diesel oil and liquefied petroleum gases.

Table 16. Emission factors for mobile combustion (default values). Values are given in net calorific value basis. Data is based on IPCC Guidelines/Mobile combustion Table 3.2.2 in kg/TJ (IPCC 2006) (kg/TJ).

	CO2 kg/TJ	CH4 kg/TJ	N2O kg/TJ
Motor Gasoline (uncontrolled) Motor Gasoline (oxidation catalyst)	69 300	33 25	3.2 8.0
Gas/Diesel Oil	74 100	3.9	3.9
Liquefied Petroleum Gases	63 100	62	0.2

IPCC Guidelines/Mobile combustion also gives N2O and CH4 emission factors for European gasoline and diesel vehicles in mg/km considering the environment (urban/cold, urban/hot, road, highway) Euro classes (pre-Euro, Euro 1, Euro 2,

12 http://lipasto.vtt.fi/yksikkopaastot/indexe.htm

13 Guidelines for National Greenhouse Gas Inventories. Vol. 2. Energy. 2006. Chapter 3 Mobile combustion. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

IPCC all reports http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Euro 3, Euro 4)) and types of vehicles (Light duty vehicles/Gasoline or Diesel and Heavy duty Tracks/Gasoline or Diesel). This data is given in IPCC Guideline Mobile Combustion (Table 3.2.5 page 3.24) and it may also be used of when considering the environmental impact from transportation of products.

Electricity and district heat

The European Life Cycle Database (ELCD)[14] database gives Life Cycle Inventory (LCI) results for the electricity supply in different European countries and for EU 27. The reference year is 2002. Energy carrier mix information is based on official statistical information including import and export. Detailed power plant models were used, which combine measured emissions plus calculated values for not measured emissions of e.g. organics or heavy metals. Each country provides a certain amount of electricity to the mix. The electricity is either produced in energy carrier specific power plants and/or energy carrier specific heat and power plants (CHP). Each country specific fuel supply (share of resources used, by import and/or domestic supply) including the country specific energy carrier properties (e.g. element and energy contents) are accounted for. Furthermore country specific technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and dedusting are considered. The data set considers the whole supply chain of the fuels from exploration over extraction and preparation to transport of fuels to the power plants. For the combined heat and power production, allocation by exergetic content is applied. For the electricity generation and by-products, e.g. gypsum, allocation by market value is applied due to no common physical properties. Within the refinery allocation by net calorific value and mass is used. For the combined crude oil, natural gas and natural gas liquids production allocation by net calorific value is applied. Some key figures of the assessment result are presented in the following Table.

14 http://lca.jrc.ec.europa.eu/lcainfohub/dataset2.vm?id=3

Table 17. LCI result for electricity for EU 27 according to ELCD.

Inputs	
Brown coal (11.9 MJ/kg LHV)	1.39 MJ (LHV)
Crude oil (42.3 MJ/kg LHV)	0.720 MJ (LHV)
Hard coal (26.3 MJ/kg LHV)	2.14 MJ (LHV)
Natural gas (44.1 MJ/kg LHV)	1.83 MJ (LHV)
Peat (8.4 MJ/kg LHV)	0.0242 MJ (LHV)
Primary energy from geothermics	0.0245 MJ (LHV)
Primary energy from hydro power	0.610 MJ (LHV)
Primary energy from solar energy	0.102 MJ (LHV)
Primary energy from wind power	0.119 MJ (LHV)
Uranium	5.00 MJ (LHV)
Wood (14.7 MJ/kg LHV)	0.0000505 MJ (LHV)
Outputs	
Electricity	3.6 MJ (1 kWh) (net calorific value)
CO2	0.558 kg
CH4	0.00108 kg
N2O	0.0000134 kg
NO2	0.00105 kg
SO2	0.00328 kg

The annual national (or regional) average production mix of the electricity may vary significantly from year to year. The variation may for instance be due to changes in electricity demand, fuel mix, technology portfolio, availability of hydro power, and net imports. For example, in Finland the minimum and maximum annual average CO2 emissions from electricity production between 1990 and 2002 vary by 20% from the average of the particular period (Soimakallio et al. 2011). Consequently, using data for only one statistical year in LCA may significantly reduce the reliability and the applicability of the results to describe the situation for other years and thus an average based on an adequate number of years is recommended.

When an electricity power plant produces multi-products such as power, heat, steam, cooling or refinery products, the problem of emission allocation is encountered. Allocation is a widely recognized and challenging methodological problem in LCA, and the selection of an allocation method typically has a significant impact on the results (Soimakallio et al. 2011). The impact of the method of allocation is especially important in Finland because of the high rate of combined heat and power production (CHP) utilization. The importance of CHP varies a lot in Europe. There are some countries like Finland and Denmark where this is very important while in other countries the percentage of gross electricity generation of combined heat and power generation is rather low (EUROSTAT[15]) (Table 18).

Table 18. Combined heat and power generation. Percentage of gross electricity generation. 2009. EUROSTAT.

EU 27	11.4%
Belgium	14.5%
Bulgaria	9.4%
Czech Republic	13.4%
Denmark	45.3%
Germany	13%
Estonia	9.2%
Ireland	6.3%
Greece	3%
Spain	7.5%
France	4.3%
Italy	10.2%
Cyprus	0.4%
Latvia	19.7%
Lithuania	13.7%
Luxembourg	10.1%
Hungary	20.5%
Malta	0%
Netherlands	32.1%
Austria	13.2%
Poland	17.2%
Portugal	11%
Romania	10.8%
Slovenia	6.2%
Slovakia	19.2%
Finland	35.8%
Sweden	10.5%
United Kingdom	6.5%
Norway	0.1%
Croatia	12.7%
Turkey	3.8%

15 http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=tsien030

Electricity and district heat produced in Finland

This section presents environmental data for Finnsih electricity and district heat calculated as an average value for years 2004–2008. Average values are recommended to be used when possible.

The models built for the calculation of the average electricity supply and heat production include fuel extraction (heavy fuel oil, hard coal, natural gas extraction, greenhouse gas emissions from peat manufacturing), electricity and heat production both in electricity and CHP plants, net imports and transmission losses. The used allocation methods for CHP are energy allocation and benefit distribution. Due to lack of data, separate heat production is taken into account only for heavy fuel oil (78% of heat produced with oil is from separate production in 2008). Other fuels are mainly used in CHP plants (75–95% of heat produced in CHP) and the shares of separate production are smaller. The assessment covers the years 2004 – 2008[16] (Table 19).

In the case of co-generation (district heating and CHP industry) there are different methods and principles how to share emissions and resources between heat and power production. The allocation procedure between heat and power can be based on energy method, exergy content, financial value, partially or fully benefit distribution method, or no sharing where emissions allocated alternatively to the on product. In the countries where most energy produced in co-generation processes, for example in Finland (2008) 21% from power and 75% from heat produced in co-generation process (CHP), the method used for allocation is extremely significant for the result. Here two types of methods are used to allocate the inputs and outputs for electricity and heat in combined production – these are the so-called benefit distribution method and energy allocation method. The energy method allocates the emissions according to the produced energies. The benefit distribution method allocates the emissions to the products relative to their production alternatives. When using the benefit distribution method, an alternative production method has to be defined for heat and electricity. In Finland, the common way of doing this is to use for electricity condensing power production based on coal use as a production alternative typically with the efficiency of roughly 40% while the efficiency value for separate heat production is assessed as roughly 90%. When calculating the result, the heat and electricity produced in CHP plants are divided by the corresponding efficiencies of the alternative production methods.

16 Calculation was done by Marjukka Kujanpää, VTT. 2012

Table 19. LCA based environmental profiles for average Finnish electricity (considering net imports).

	Benefit		Energy	
	Electricity	District heat	Electricity	District heat
CO2 fossil, kg/MWh	309	236	222	273
CO2 biogenic, kg/MWh	121	134	67.5	160
CH4, kg/MWh	0.821	0.364	0.709	0.424
N2O, kg/MWh	0.000654	0.000397	0.000523	0.000448
GHG, kg/MWh	330	245	240	283
Materials, mainly fossil, kg/MWh	113	69.3	90.8	79.7
Materials, wood, kg/MWh	25.5	52.7	25.8	63.4

3.3.4 Building products

SUSREF made use of the ELCD data[17] for building materials when comparing the environmental impacts of altenative refurbishment concepts. However, because there is very limited data available, the project mainly used national data formulated in Finland and other countries involved in the project.

Appendix 1 gives examples of data that taken from the above mentioned databases or developed on the basis of nationally recognized systems. This data shows examples of information that can be used in calculations.

When developing EPDs in Norway two different electricity mixes have been used:

1. Production in Norway: the electricity used refers to the Norwegian mix given by the Nordel's annual statistics. In 2007 this included the following shares: 96% production in Norway, 3% import from Sweden and 1% import from Finland/Denmark. This is modelled in Gabi (ELCD data can be used).
2. Nordic average is also used.

A discussion is going on about the electricity mix that should be used in LCA, especially when looking at zero emission buildings (ZEB, www.zeb.no). A marginal reflection and scenario analysis for future electricity mix have been suggested.

3.3.5 Environmental assessment

When assessing the environmental impact of alternative refurbishment concepts it is recommended to consider at least the following aspects:

17 http://lca.jrc.ec.europa.eu/lcainfohub/datasetCategories.vm

- use of renewable energy
- use of non-renewable energy
- use of renewable natural raw materials
- use of non-renewable natural raw materials
- greenhouse gas emissions
- wastes (problem wastes, other wastes).

Embodied energy should be dealt with as a separate parameter.

Carbon footprint assessed on life cycle bases in terms of greenhouse gases is the main environmental assessment criteria in SUSREF. When assessing the total greenhouse gases the factors presented in IPCC 4th Assessment Report[18], Chapter 2 and Table 2.14 (Lifetimes, radiative efficiencies and direct (except for CH4) GWPs relative to CO2) have been used in calculations. According to this Table the global warming potentials for 100 years' time horizon for carbon dioxide, methane and nitrous oxide are

- 1 for CO_2
- 25 for CH_4
- 298 for N_2O.

The system boundaries are defined so that the following phases should be taken into account:

- demolition and disposal of those parts of the old structure that will be removed
- manufacture (from cradle to gate) and transportation of new products
- construction of the new structure considering the material losses
- manufacture and transportation of components and materials (such as paints) that are needed during the service life of the concept.

In most cases, the first issue may be excluded if the alternative refurbishment concepts require the removal of equal parts from the existing walls. In practise, the construction phase may sometimes also be excluded because of the minor impact but this should be assessed separately in each case.

Figure 18 presents the system boundaries for the basic cases.

18 http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

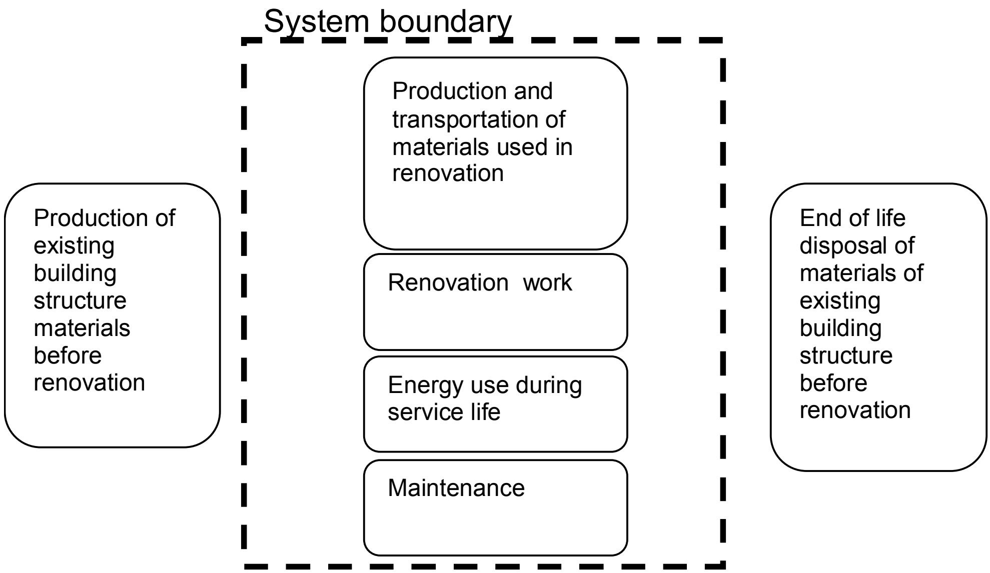


Figure 18. System boundaries for the assessment of alternative concepts of refurbishment.

Appendix 2 gives an example about the basic approach when assessing the environmental impacts of a refurbishment concept.

3.4 Life cycle costs

The European Commission has developed an EU-wide Life Cycle Costing (LCC) methodological framework for buildings and constructed assets (Langdon 2007). The method is based on corresponding ISO standard (ISO 15686-6, 2008). Within the context of the Lead Market Initiative the European Commission did also develop a promotion campaign of LCC with case studies according to which The methodology was proven to be very useful and its steps fitted well within existing LCC practices in the countries analysed (Langdon 2010).

According to ISO 15686-5 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 throughout the lifecycle. The application of LCC methodology is based on systematic analysis process as shown in the following figure.

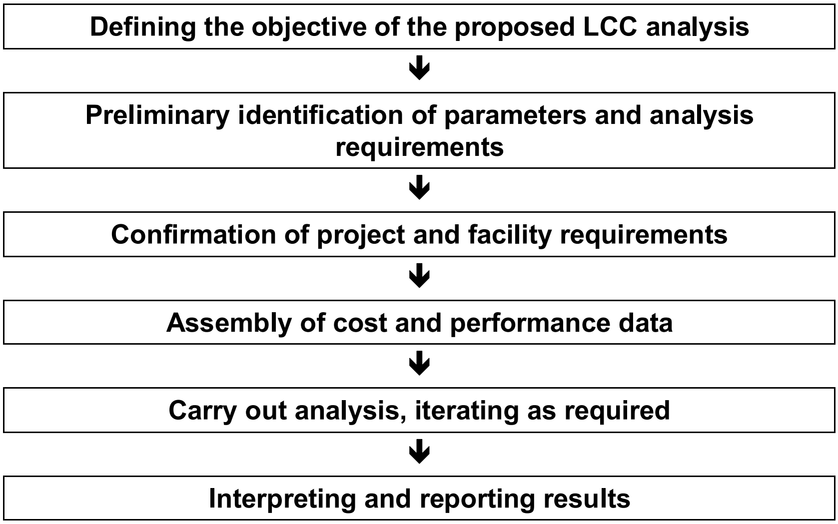


Figure 19. LCC Methodology.

The LCC analysis 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. The main content covers principles of life-cycle economics with reference to

- design options/alternatives
- investment options
- decision variables and
- uncertainty and risk.

Because of the predictive nature of life cycle costing methods, sensitivity analyses are often important in the connection of life cycle economics. Sensitivity analysis may be based on classification including for example the three steps: optimistic – probable – pessimistic.

Economical analyses may also be drawn up in early stages of building design if there is information available on reference data of building related life cycle costs. Figure outlines the possibilities to utilise life-cycle based decision making for example when comparing alternative technical solutions or when analysing cost-effectiveness, profit and cash flows.

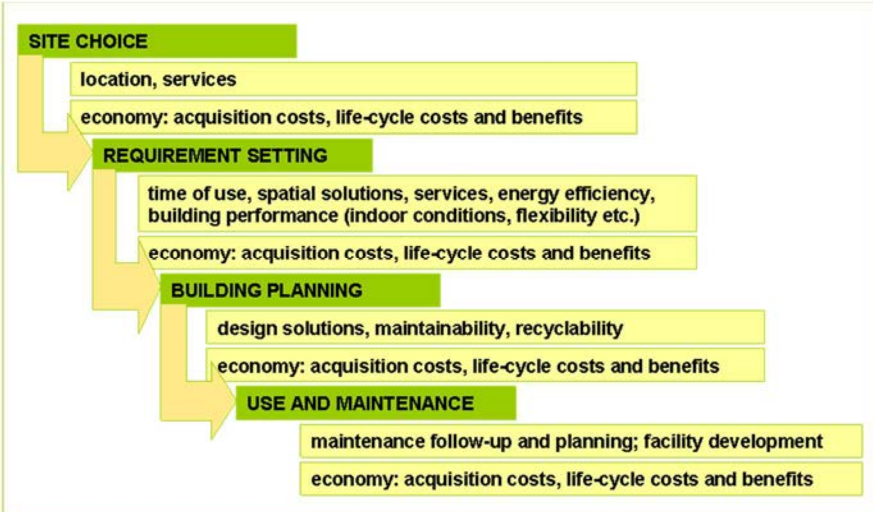


Figure 20. Main phases and objects of life-cycle based decision making.

Economical analyses are typically presented in terms of net present values; financial costs are taken into account, no discount rate is used and profit rates are calculated considering extra costs and costs savings.

Appendix 3 shows examples of analyses carried out by VTT with regard to real cases of Senate Properties (Senate Properties owns and manages the public state owned building stock in Finland).

3.5 Building physical modelling

3.5.1 Objectives

This Chapter gives guidelines for the use of building physical modelling methods and tools in the development of sustainable refurbishment technologies for external walls. The objective is to give guidelines for how knowledge on building physics and modelling methods and tools could be used in the development of sustainable refurbishment technologies for external walls. With the hygrothermal modelling and analysis of the results, existing and innovative refurbishment methods and concepts can be evaluated in terms of their hygrothermal performance in order to identify thermal bridges, potential for moisture related problems and other malfunctions. The development process can be seen as an iteration process where the best solution for any actual case is found by optimising, among others,

- thermal performance of the envelope: reduction of the heat losses through the envelope, minimising thermal bridges

- moisture performance of the envelope: ensuring drying capacity, avoiding condensation
- durability of the constructions: reduction of the risk for mould and decay
- indoor air quality and comfort: thermal symmetry, no draft, control of humidity.

The building physics modelling is here understood as the analysis on the constructions only. The whole building analysis is the subject in other reports that concern assessment of the building energy consumption, and give a more complete idea of what impact the development of sustainable refurbishment technologies for external walls has on the space heating/cooling energy demand and on the resulting indoor climate.

The building physical assessment has an important role in the overall technical assessment of the suitability of the refurbishment concepts. It ensures the physical performance and durability of the structures in the same time that the energy and material use related environmental effects are minimised. The basic idea is to test how far we can go with improving the energy performance without causing problems in terms of other criteria.

These assessment instructions/guidelines are relevant when analysing the hygrothermal performance of the existing constructions and when finding sustainable refurbishment solutions.

3.5.2 Methods and tools for building physical assessment

Building physics[19] is about understanding and analysing the heat, air and moisture (HAM) interactions – transport and storage – in and around building materials and constructions. This complicated theoretical analysis is typically implemented in more and more advanced simulation and modelling tools. The simulation algorithms solve the coupled heat, air and moisture (= hygrothermal) states throughout the control volume to be studied as a function of time and place. Therefore, the dynamic simulations with hygrothermal simulation tools are an important and even necessary part of the assessment work. Some of the most used and verified simulation tools for hygrothermal analysis of building constructions are WUFI, DELPHIN and Match. In addition there are quite a few tools for pure thermal assessment, mostly two dimensional simulation tools for assessment of the thermal bridges. The coupled heat and moisture transport, however, is necessary to be analysed in order to assess almost any moisture related performance criteria.

19 The basic theory of the building physics will not be treated in this report. We refer to any basic theory book about coupled heat, air and moisture transport and storage.

The hygrothermal impacts on a building and the thermal envelope are illustrated in the following Figure 21.

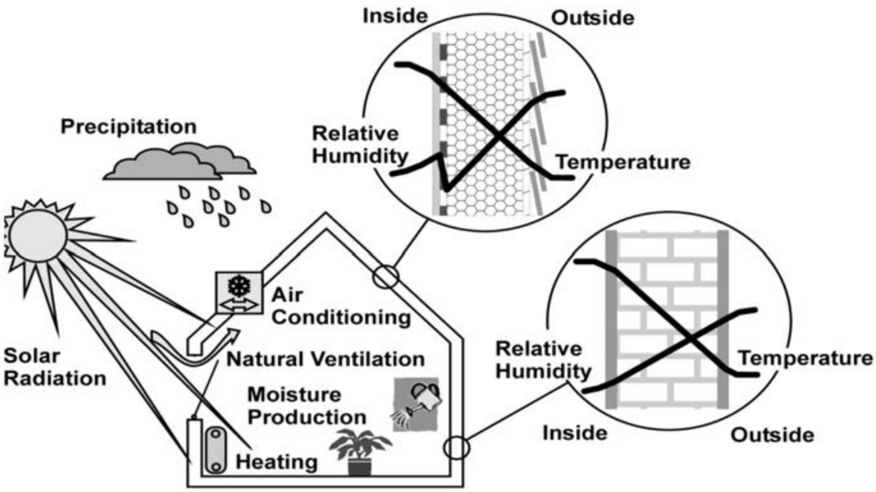


Figure 21. Illustration of the HAM impacts and mechanisms in and around an exterior wall (Sedlbauer et al. 2004).

Moisture in a porous material can be transported either as water vapour or as liquid water, or as a combination of these two phases in the pores. The solid matrix is normally not active in the transport. Moisture transport can either be diffusive or convective. Diffusive transport is proportional to the gradient of the driving force(s), a proportionality coefficient being a material parameter which is determined experimentally, e.g. water vapour permeability. The convective flux is a product of the vehicle flux, e.g. air, and the transported density of moisture.

All the simulation tools for hygrothermal analysis consider usually water vapour diffusion that is transport of moisture in the air, typically in the pores of a material. This is the predominant transport mechanism in a very porous material (e.g. mineral wool). If the pores of the material are very microscopic (e.g. concrete) and/or the material is very wet (e.g. wet wood), the capillary conduction will be dominating. This capillary transport is included at least in WUFI, DELPHIN and Match. In some cases there may exist also surface diffusion. In Figure 22 are shown some of the central moisture transport mechanisms within a porous material and some of the driving potentials. Beside the water vapour pressure and the moisture content, the temperature is the main driving force for coupled heat, air and moisture transport.

Convective moisture transfer takes place in air gaps of a construction and in very open porous materials like light weight insulation materials. The driving force can be the air pressure difference due to the temperature gradient within the material that enables natural convection. Or the convection can be forced by air pressure through any air leakages in the envelope. Hygrothermal convection is normally modelled physically correct only in the most advanced 2D tools.

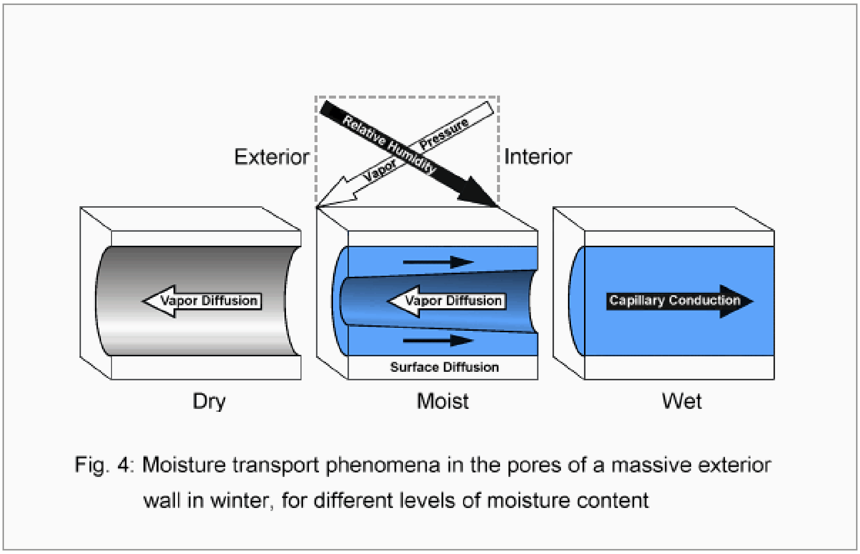


Figure 22. The different transport mechanisms of moisture within a porous building material. The transport mechanism is governed by the moisture content and the porosity of the material. From[20].

Depending on the construction type and refurbishment method to be analysed, the most suitable calculation and simulation tools should be chosen.

- 1D coupled heat and moisture calculations tools – 1D HAM -tools (e.g. WUFI-Pro[21], Match[22]) are the best choice for constructions and solutions consisting of just homogenous layers. Ventilated cavities can be studied simplified with these tools, too.
- 2D coupled heat and moisture calculations tools – 2D HAM -tools (e.g. WUFI2D, DELPHIN[23]) should be used for constructions containing inhomogeneous layers, e.g. stone walls, fastenings, and ventilation

20 http://www.wufi-pro.com/

21 http://www.wufi-pro.com/. The simulation tool is based on the PhD dissertation: Künzel H.M.: Verfahren zur ein- und zweidimensionalen Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen mit einfachen Kennwerten; Dissertation Universität Stuttgart 1994.

22 http://www.match-box.dk/

23 http://www.bauklimatik-dresden.de/delphin/

cavities. 3D effects must be taken into account by qualified modification of the model, together with a possible 3D thermal calculation.

- Constructions with complicated cavities or elements with active fluids like air or water/brine should be modelled with multi-physics or CFD-tools (Computational Fluid Dynamics tools) (e.g. Comsol[24], Fluent[25]).

Generally, one-dimensional (1D) HAM-tools are sufficient for most of the analysis with skilled expert use. The computation of coupled heat and moisture transport in two dimensions (2D) is usually very time-consuming and the detailed information from a 2D or even 3D calculation may be overruled by other uncertainties. For instance, the thick stone wall constructions may prove a problem because many stone types are impervious to moisture penetration but the mortar in between stones is not. Strictly speaking, this should require a 2D model, but it may prove difficult to get reliable input data for all of the various material properties. Pure heat transmission tools (in 2D and 3D) are very usable for optimisation of the thermal bridges and assessment of the critical surface temperatures for e.g. mould risk.

Basically, advanced state-of-art building physics tools are recommended for research purposes in order to understand the phenomena as far as possible. Simpler tools and methods, engineering tools, are often the best way to analyse most of the cases and especially any real life problems.

The simulation output is typically the temperature and moisture content states throughout the defined construction as a function of time. This output is then post-processed in order to give input for the assessment. The performance criteria used are described in the next chapter.

3.5.3 Performance criteria for building physical assessment

When assessing building envelope constructions from the viewpoint of building physics, following different sub-areas of performance, which form the overall performance, are included in this study:

1. thermal performance of the envelope
2. moisture performance and durability of the constructions
3. indoor air quality and comfort.

The assessment criteria for these subjects will be presented and shortly defined and motivated in this section.

24 http://www.comsol.com/

25 http://www.fluent.com/

3.5.3.1 Thermal performance of the envelope

The thermal performance of the envelope is basically evaluated on the basis of the heat losses through the envelope. This includes action on two levels: increasing the thermal insulation of the envelope and minimising the thermal bridges:

1. The overall U-value of the construction should be low in order to minimize the energy use for space heating and cooling.
2. The effect of thermal bridges should be minimized in order to avoid additional heat losses and low local surface temperatures, which can cause local discomfort and unwanted micro-climate for biological growth.

3.5.3.2 Insulation thickness – target U-values

The resulting U-values for different construction types and in different climates will be a result of the entire assessment method developed within this SUSREF project. And as the building space heating and cooling energy demand is a function of the whole building and can only be determined with simulation of a whole building, some intermediate targets for U-values must be – and were – set in order to be able to perform the analysis on the wall component level.

The target for the thermal performance is of course very dependent on the actual motivation of any future refurbishment project. But in order to find any kind of optimum for a construction from the building physical view point, a certain range of U-values should be analysed. An example of setting the target u-values is given below.

The starting point for setting these target values was taken from a Eurima project from 2007 by Ecofys (Boermans & Petersdorf 2007) that found economically recommendable U-values for 100 cities in Europe. The determined values for walls according to two different price scenarios in the regions studied are found in Table 20. Here only selected cities relevant for the partners in SUSREF are included in this overview.

Table 20. Economically recommendable U-values [W/(m2K)] for walls in selected cities according to Boermans & Petersdorf 2007.

City	Country	WEO reference	Peak price scenario
Tallinn	Estonia	0.19	0.17
Helsinki	Finland	0.18	0.17
Oulu	Finland	0.17	0.15
Bergen	Norway	0.21	0.18
Oslo	Norway	0.19	0.17
Madrid	Spain	0.26	0.23
London	United Kingdom	0.23	0.19
Manchester	United Kingdom	0.21	0.18

The U-values in Table 21 were slightly simplified (= rounded up or down) for this study and a parameter variation was introduced as a lower and upper value. A graphical presentation of these values together with the representative heating degree days (HDD) for the same locations is given in the following Figure 23.

Table 21. Recommended target U-values for the hygrothermal analysis of walls.

	Target U-value [W/(m^{2}K)]		
Location	Lower value (70%)	Economic optimum (rounded value)	Upper value (140%)
Oulu	0.105	0.15	0.21
Helsinki	0.105	0.15	0.21
Tallinn	0.14	0.2	0.28
Oslo	0.14	0.2	0.28
Bergen	0.14	0.2	0.28
London	0.175	0.25	0.35
Manchester	0.14	0.2	0.28
Bilbao	0.175	0.25	0.35
Madrid	0.175	0.25	0.35

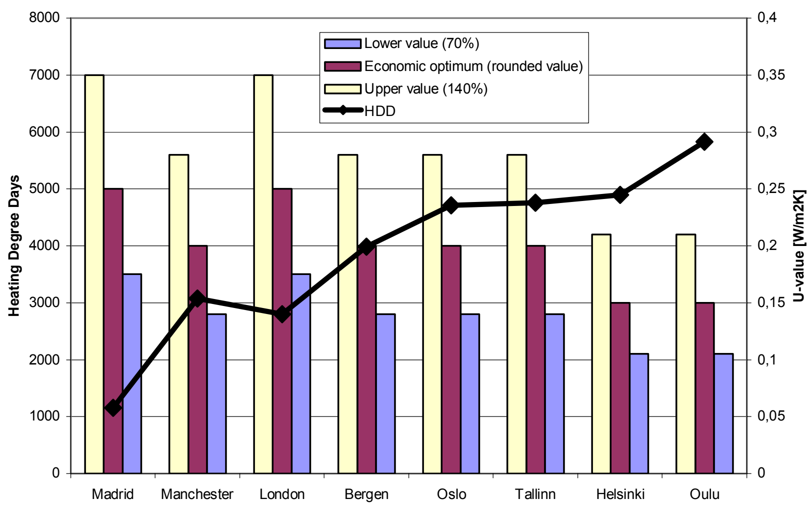


Figure 23. The intermediate target U-values together with heating degree days (HDD) for same locations.

This way of setting the target U-values can determine the starting point for the additional insulation layers and thicknesses of these. For the historical heritage buildings, an alternative approach solutions and U-values are most likely to be considered.

3.5.3.3 Thermal bridge effects

Besides the low target U-values, which are motivated by environmental, financial and legislative reasons, the constructions should be designed such a way that the thermal bridges are minimised. Thermal bridges can occur in different ways:

- systemically throughout the construction, e.g. wooden studs
- due to the building geometry, e.g. corners
- connections between different building parts, e.g. window installations.

Thermal bridges will influence the heat losses and indoor surface temperatures (more about this in Chapter 3.5.12 Indoor air quality and comfort).

The thermal performance and quality of constructions can also be expressed as a temperature factor (form factor for the thermal bridge effects) f_{Rsi} given in Equation 1. This factor expresses the ratio of the temperature difference between indoor surface and outdoor air to the total temperature difference.

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} = 1 - U \cdot R_{si} \tag{1}$$

In case of a pronounced thermal bridge, the indoor surface temperature is low and therefore the ratio small. Therefore, the higher $f_{Rsi,}$ the smaller is the thermal bridge effect.

f_{Rsi} is determined for typical, dimensioning, winter conditions, for example θ_i = 20 °C and θe = -5 °C (= *average temperature for the coldest month*). This temperature factor is recommended typically to have values over 0.7. Any value under this value and resulting moisture problems can be seen as a consequence of too poor thermal quality of the construction, thus the low indoor surface temperature, in combination with high relative humidity of the indoor air while for f_{Rsi} > 0.7 the moisture problems can mostly be allocated to the high relative humidity of the air. The resulting surface moisture conditions are a function of the indoor relative humidity and the average outdoor temperature in the coldest part of the year.

Also homogenous constructions can be evaluated with respect to the average minimum surface temperature with the latter part of Equation 2, but this is only relevant for homogeneous constructions when the U-value is above 1 W/m^{2}K.

Below is shown two diagrams for simplified design against mould growth (Figure 24) or condensation (Figure 25), where the limit value for f_{Rsi} can be found if the indoor RH and external air temperature the coldest month are given. These are simplified curves based on the calculation method in EN ISO 13788.

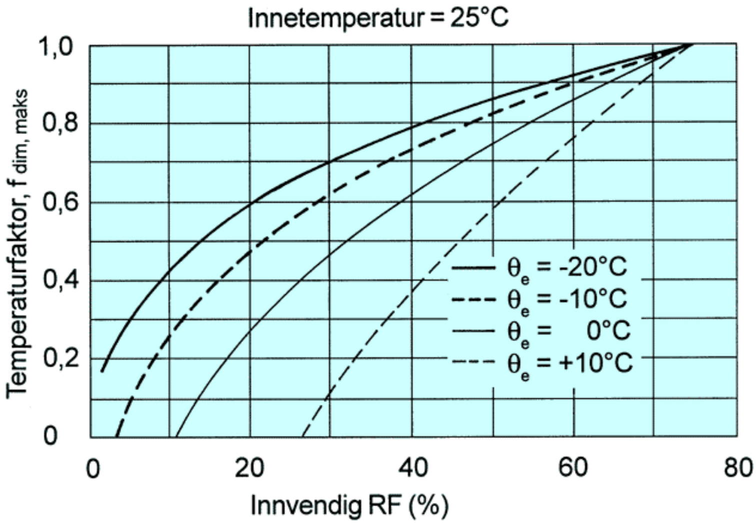


Figure 24. The relation between temperature factor ($f_{dim,maks}$, Y-axis), relative humidity (X-axis) at different average outdoor temperatures regarding the risk of mould growth. Indoor temperature = 25 °C (Anon 1999).

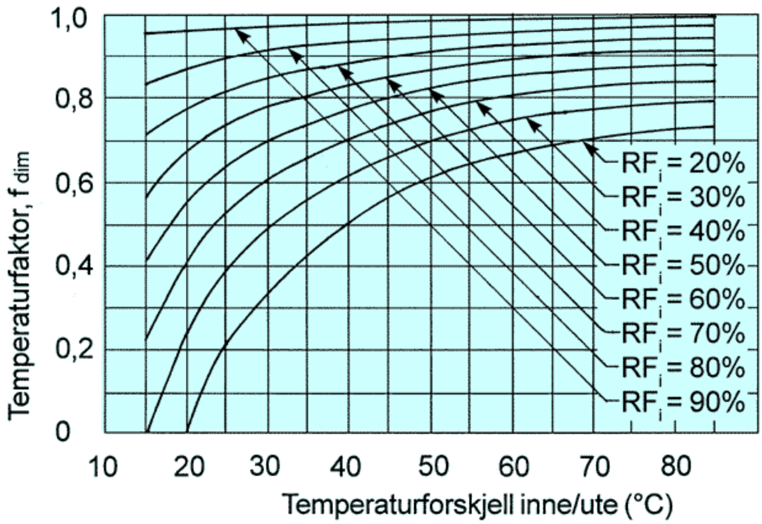


Figure 25. Dimensioning temperature factors f_{dim} concerning condensation at different indoor air relative humidifies and temperature differences (Anon 1999).

3.5.4 Moisture performance and durability of the constructions

The moisture performance of the envelope is central for the durability of the constructions: Moisture plays the main role in most of the decay and deterioration processes, e.g. growth of algae and mould, decay fungi, frost damage and corrosion. The conditions in the constructions should not exceed critical limits for moisture and temperature, which – if exceeded – will lead to these durability problems. Risk of condensation will typically lead to these other problems and, in addition, reduce the thermal insulation effect of the refurbished – or any – constructions.

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- keeping the construction dry (e.g. avoiding condensation, penetration of driving rain)
- choosing suitable materials (e.g. inorganic materials to exposed locations)
- ensuring drying capacity (e.g. with ventilation and right placement of materials with different water vapour diffusion permeabilities).

An illustration of some of these critical limits is found in Figure 26 that gives some "safe" limits for mould growth in different building materials. The area above the curves expresses the critical conditions for mould growth.

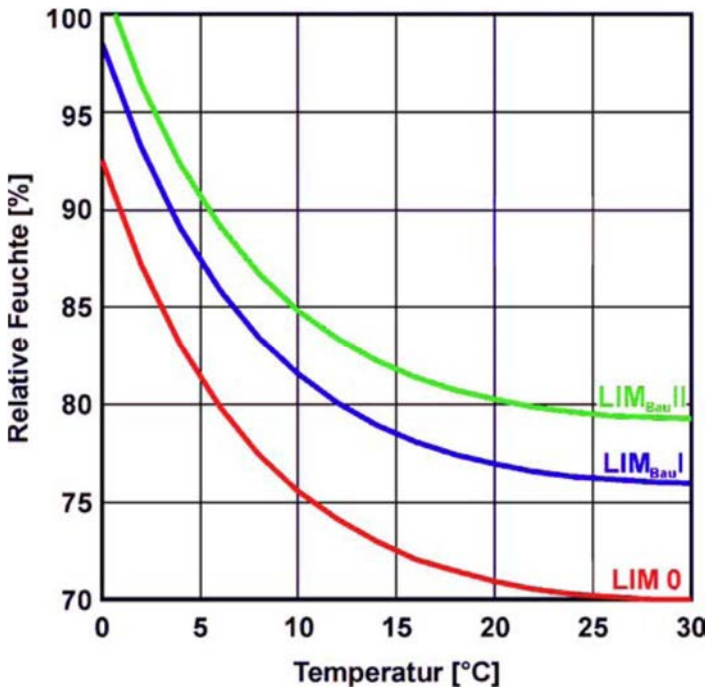


Figure 26. "Safe" limits for avoiding mould growth for different material classes.
LIM 0: Optimal culture medium, represents the maximum growth possible for any mould found in buildings.
LIM I: Bio-utilizable substrates, such as wall paper, plaster board, building products made of biologically degradable materials, materials for permanently elastic joints, strongly contaminated surfaces.
LIM II: Less bio-utilizable substrates with porous structure, such as plasters, mineral building materials, certain woods, insulating materials not belonging to group I.
Inert substrates such as metals, foils, glass and tiles are usually not affected by mould, unless contaminated. From WufiBio manual (Sedlbauer 2001).

When performing building physical dynamic simulations, the resulting temperature and relative humidity hourly values on a material surface can for example be used for an evaluation of the risk for mould growth on this surface with so called TOW, time of wetness (= number of hours during a year when the given limits are exceeded.). Limits in the Figure 26 can be used to calculate number of yearly hours, when these values are exceeded. When n_{hours} = 0, the construction can be evaluated as mould safe. TOW's can be used to compare different solutions: i.e. which solution gives the lowest TOW's.

Mould growth is one of the first signs of biological deterioration caused by excess of moisture, and therefore mould growth can be used as one of the best hygrothermal performance criteria of building structures. Mould does not deteriorate the material, but it is a sign of too high moisture content and it represents a risk for other moisture caused problems, like decay (see more about decay in next chapter). Mould affects the appearance of the surface and it can severely affect the indoor air quality when the growth is in contact with indoor air or with the leakage air flowing into the room space.

The time of wetness -method is a simple way of assessing the hygrothermal simulations. However, there exist also dynamic models for estimation of the risk for mould growth (Hukka and Viitanen 1999). The dynamic nature of these models results in outcomes with much more information, this requires more expertise to assess.

In the following, some of the central moisture related assessment factors are presented.

3.5.5 Drying capacity

The drying capacity is traditionally used as a security for the main strategy of keeping the construction dry. For example, in case of accidents, which involve water damage, the drying capacity will reduce the risk for mould growth. The drying mechanisms are also widely calculated in the construction process and time tables, and allow a more rapid process.

Therefore one of the central criteria is the amount of accumulated water in the construction during a year Δw [kg/m^2/y]:

$$\Delta w = w_{end} - w_{start} \quad (2)$$

A well performing construction should not accumulate moisture at all and therefore the negative accumulation should be as high as possible to ensure large drying potential.

3.5.6 Mould growth

Mould growth is biological growth on almost any material surface. The mould growth is highly dependent on the temperature and especially of the moisture activity of the surface material. The time needed for the spores to germinate and the mould growth to start is a function of the hygrothermal conditions. In addition, the growth is dependent on the organic material available as nutrient. Figure 27 illustrates some threshold values for time, temperature and water activity (= relative humidity) for constant exposure for pine sap wood, which is one of the most sensible materials with respect to mould growth.

The mould growth is a general and common definition for the biological growth based on mould fungi that include several species. When talking about Mould Index etc, it includes all fungi species.

Mould spores are naturally everywhere and therefore hard to avoid especially on the exterior part of the building constructions. In addition, the conditions of the exterior parts of the building envelope are close to exterior weather conditions, which in many climate regions are favourable for mould growth (see e.g. Figure 27).

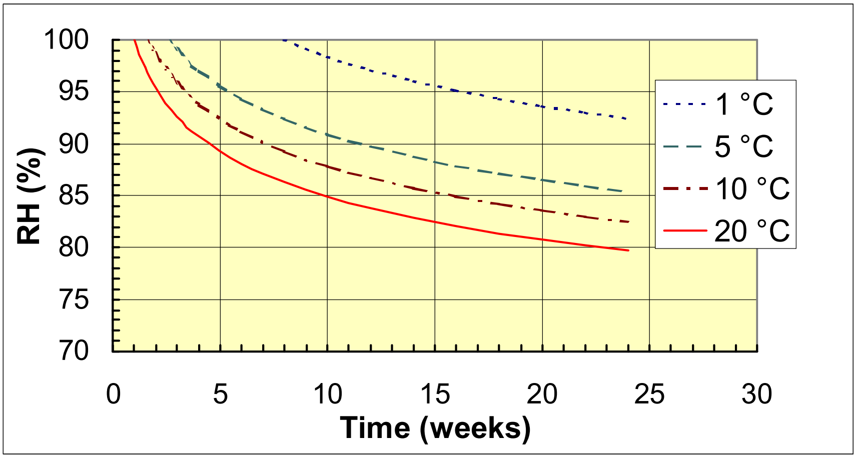
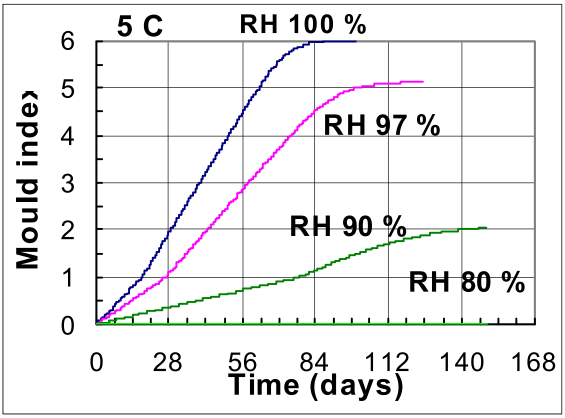


Figure 27. Critical conditions for mould growth in pine sap wood. Constant conditions (Viitanen et al. 2000).

After the germination of the mould spores has taken place, the mould is growing in different intensities, depending on the conditions. There are several methods to assess the severity of the mould growth and one of them is the Mould index, which is defined as a scale from 0–6 (see below list). Figure 28 and Figure 29 illustrate the mould index levels.



0 = no growth

1 = some initial growth (microscopy)

2 = moderate growth, local colonies, coverage > 10% (microscopy)

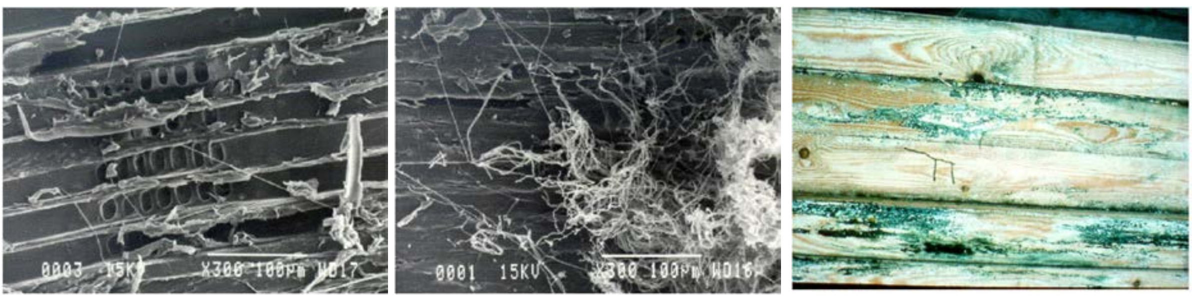
3 = some growth (visually detected, < 10%) or < 50% coverage (microscopy)

4 = mould growth coverage 10–50% (visual) or coverage > 50 (microscopy)

5 = plenty of growth, coverage > 50 (visual)

6 = heavy and tight growth, coverage 100%

Figure 28. Development of the mould index as a function of time for different constant exposures at 5 °C. Pine sapwood. [8] The list gives the growth criteria for the different mould index levels (Ojanen et al. 2010).



Mould index 1 (start of growth) | Mould index 4–5 (plenty of growth) | Mould index 6 (tight coverage)

Figure 29. Illustration of the different mould index levels.

Numerical simulation of heat, air and moisture performance of building structures generates the prediction of hygrothermal conditions in different parts of the analyzed structure as described earlier in this report. There have been some attempts to develop numerical models for the mould growth by post processing this data in order to evaluate the risks connected to overall performance, service life, interaction with indoor climate conditions or structural safety. (Hukka & Viitanen 1999, Viitanen et al. 2000, Sedlbauer 2001, Clarke et al. 1998, Hens 1999).

The mould model developed by Viitanen was originally based on the estimation of mould growth on wooden materials, recently it has been extended for several other building materials. The model can be used parallel with heat, air and moisture simulation models or as a post-processing tool.

The first version of the mould growth model was based on large laboratory studies with pine sapwood. The mould growth intensities were determined at the constant conditions. In the later stages, studies in varied and fluctuated humidity conditions were performed and based on these studies, mould growth model was presented by Viitanen et. al. 2011.

$$\frac{dM}{dt} = \frac{1}{t_m} \cdot k_1 \cdot k_2 \tag{3}$$

where

t_m is the time needed to start the mould growth on a sawn surface of pine. This has been experimentally determined and modelled as follows:

$$t_m = 7 \cdot 24 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 66.02) \quad hours \tag{4}$$

where

T is temperature, [°C]

RH relative humidity, [%]

k_1 represents the intensity of the mould growth for different materials at different phases of mould growth ($M \leq 1$ and $M > 1$) as related to the sawn surface of pine. The values of k_1 for different sensitivity classes (materials) are presented in the table below.

The factor k_2 represents the moderation of the growth intensity when the mould index (M) level approaches the maximum peak value in the range of $4 < M < 6$.

$$k_2 = \max\left[1 - \exp\left[2.3 \cdot (M - M_{\max})\right], 0\right] \tag{5}$$

Where the maximum mould index M_{max} level depends on the current conditions as follows:

$$M_{\max} = A + B \cdot \frac{RH_{crit} - RH}{RH_{crit} - 100} - C \cdot \left(\frac{RH_{crit} - RH}{RH_{crit} - 100}\right)^2 \tag{6}$$

The constants A, B and C and the critical relative humidity RH_{crit} (= RH_{min}) are defined separately for each sensitivity class.

Table 22. Parameters of the sensitivity classes of the mould model.

Sensitivity class	Examples of materials	k_1		k_2 (M_{max})			RH_{min}
		M < 1	M > 1	A	B	C	%
Very sensititive (vs)	Pine sapwood	1	2	1	7	2	80
Sensitive (s)	Glued wooden boards, PUR with paper surface Spruce	0.578	0.386	0.3	6	1	80
Medium resistant (mr)	Concrete, aerated and cellular concrete, glass wool, polyester wool	0.072	0.097	0	5	1.5	85
Resistant (r)	PUR polished surface, glass	0.033	0.014	0	3	1	85

The decline of the mould growth has been modelled based on cyclic changes of humidity conditions. The decline of mould growth index, that is recovery, is determined using the rules in Equation:

$$\frac{dM}{dt}=\begin{cases}-0.00133, \; when \; t-t_1 \le 6h \\ 0, \quad when \; 6<t-t_1 \le 24h \\ -0.000667, \; when \; t-t_1 > 24h\end{cases} \tag{7}$$

Where t_1 is the initiation time of the dry period.

Figure 30 illustrates the predicted mould growth given by some of the models with selected assumptions and a comparison with measured data. This figure illustrates also that the mould growth simulation models do not guarantee any exact prediction of mould in different cases and conditions. The variation of the parameter sensitivities is high, estimation of a product sensitivity class is difficult without testing, the surface treatments may enhance or reduce growth potential, different mould species have different requirements for growth and the evaluation of the actual conditions in the critical material layers may include uncertainties. Nevertheless, the motivation to use and develop numerical mould growth models and application of them is to give tools for better prediction and evaluation of the risks for biological growth on structure surfaces and to find the best solutions to ensure safe performance for the building and the indoor climate.

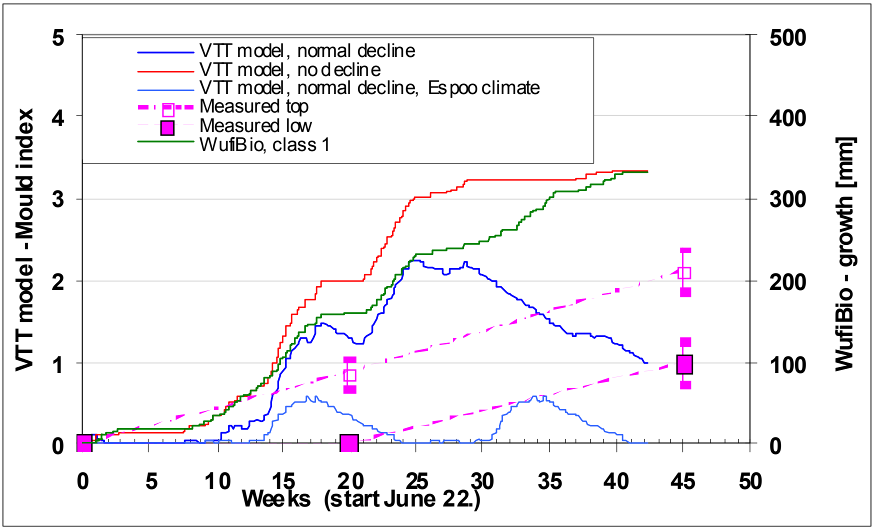


Figure 30. An example on the prediction of the mould growth with numerical, dynamic models and comparison with the measured (= observed) mould growth. The scales on first and second y-axis are set arbitrary. (Ojanen et al 2010)

Even though these numerical mould growth models are relatively easy to implement as post processing of hourly temperature and relative humidity results of the hygrothermal simulations, the correct interpretation of the results is often only possible with experience and expert knowledge. Therefore, there is a need for some far more simple evaluation methods that are suitable for comparison and the assessment of the risk.

One of the simplest post processing and evaluation methods is to determine time of wetness (TOW) for given threshold values of T and RH. (TOW is usually used for assessing the corrosion risks.) Figure 26 gives some "safe" limits for mould growth in different building materials.

ASHRAE[26] has given a set of simple criteria for evaluating the moisture performance of constructions by using the threshold values determined by favourable conditions for mould growth, like in Figure 26. See Table 23. The use of this kind of criteria for assessment of the performance of wall assemblies is found e.g. in a study of the influence of the solar driven water vapour transport on the moisture performance of the constructions.

26 American Society of Heating, Refrigerating and Air-Conditioning Engineers. www.ashrae.com

Table 23. Performance criteria for evaluation of building constructions by ASHRAE standard method 160. The values give the favourable values for mould growth.

Criterion 1: 30-day running average	RH > 80%	5 °C < T < 40 °C
Criterion 2: 7-day running average	RH > 98%	5 °C < T < 40 °C
Criterion 3: 24-hour running average	RH = 100%	5 °C < T < 40 °C

3.5.7 Growth of algae on exterior surfaces

Another biological growth type unwanted in building constructions is the algae growth on the exterior surface of the building envelope. The problem with these typically blue and green algae, typically on north oriented surfaces, is mostly aesthetic but, nevertheless, unwanted.

The increasing problem with algae is partly a consequent of better insulation levels that reduces the exterior surface temperature. Algae need liquid water and this is available from driving rain and especially from condensed water on the facade during night under-cooling. Therefore, the performance criteria in order to avoid algae is to avoid liquid water and condensate on a exterior surface, i.e. RH < 100%.

Beside the U-value of the construction, the exterior surface temperature and relative humidity are function of the surface material properties: radiation properties (especially long wave emissivity) and heat and moisture absorption capacity. Experimental studies and simulation of the results show that darker and moisture absorbing surface materials reduce the algae access to condensate water. More about the biological growth on exterior surfaces can be found e.g. in (Møller 2003).

3.5.8 Decay of wooden constructions

The critical moisture levels are clearly higher for decay than mould. Typically the relative humidity must be higher than 95% for long periods in order to give favourable conditions for decay fungi. Figure 31 shows some critical limits of temperature and relative humidity of pine sapwood under constant exposure.

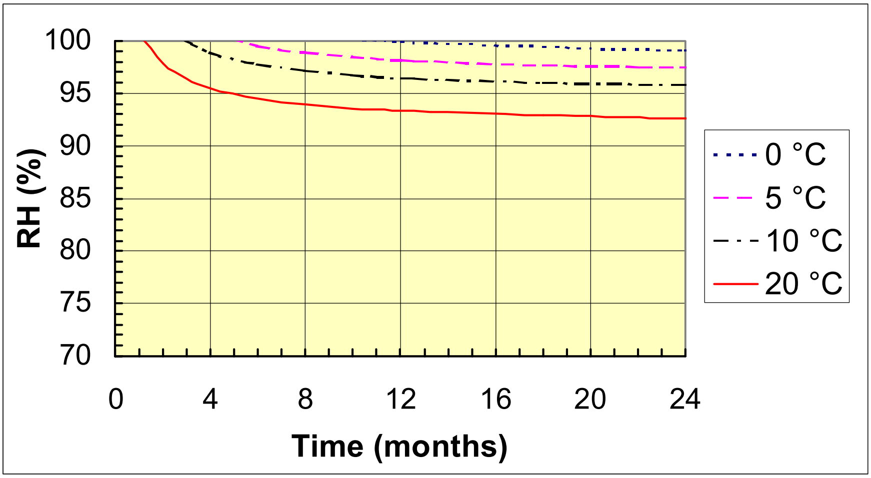


Figure 31. Critical conditions for decay development in pine sap wood. Constant conditions (Viitanen et al. 2010).

Within a recent research project focusing on the durability of wooden exterior sheetings, a numerical model for the decay development was developed, based on a regression model of a general isoplet for decay development in untreated pine sapwood (Viitanen 1996). This model was combined with the historical meteorological data to generate European decay maps (Figure 32). This dynamic decay model can also be used to post process the results from the building physical simulations in order to assess the durability of the wooden constructions exposed to different conditions and the effects of e.g. insulation thickness and material choices.

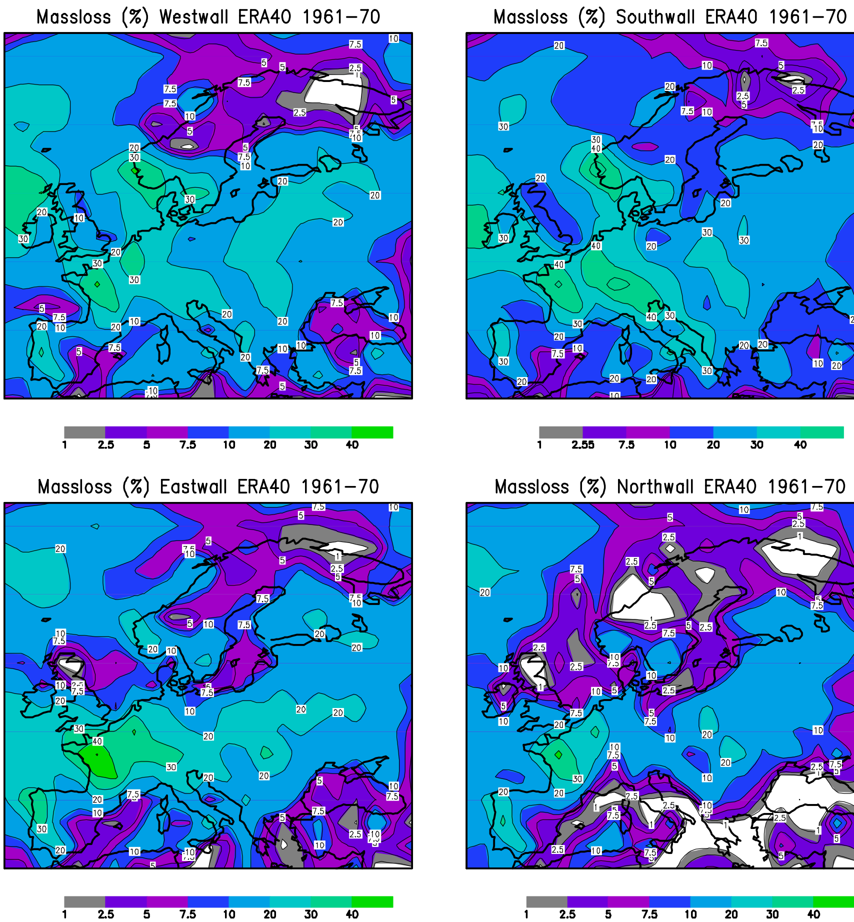


Figure 32. Modelled mass loss (in %) of pine wood on differently aligned vertical surfaces exposed to driving rain in ten years in Europe (Viitanen et al. 2010)

3.5.9 Decay of and damage to insulation products

The impact of high levels of moisture on insulation in a construction can be damaging to the performance of the wall. A frequent cause of moisture build up is interstitial condensation and since the presence of moisture lowers the insulating value of most materials, this can create a vicious circle, leading to more frequent occurrences of interstitial condensation and greater heat loss. The mould growth potential in the insulation materials can be analysed with the criteria for mould growth.

The increased heat transport would normally speed the drying out of the external face of the insulation i.e. mineral wool. Under freezing conditions, formation of ice may block vapour diffusion and lead to such effects. Geving and

Thue (2002) claims that vapour diffusion in practice is not greatly affected by formation of ice, nor is water transport at near (sub) zero temperatures.

3.5.10 Frost damage, carbonation and reinforcement corrosion

Frost damage occurs typically when a rigid porous material like concrete or masonry brick has very high water content and the temperature decreases below zero.

Performance criteria for constructions in order to avoid frost damages can be defined with the moisture content that should not exceed the critical value of saturation fraction, which theoretically is 0.917. The critical saturation fraction is very different for different materials and can/should be determined experimentally. Examples for e.g. reduction of the E-module of natural stone as a function of the water saturation degree, tested for 1, 19 and 110 freeze and thaw cycles is given in Fagerlund 1972. Frost damage criteria are not relevant in warm climates.

Frost damage

In the VTT simulation model (Vesikari 1999) the occurrence and propagation of frost damage is evaluated based on the theory of critical degree of saturation developed by 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.

When evaluating the critical degree of water saturation the amount of air porosity and the form of air pore distribution are considered. The air pores are assumed to get filled with water in the order of their size, from the smallest to the largest, and the critical amount of water in the air pores is determined based on the critical distance of air pores based on the Powers theory ($V_{air;\,cr}$). Any changes in the concrete mix design affect the critical amount of water filled air pores (and consequently the critical degree of water saturation).

$$S_{cr} = \frac{V_{cap} + V_{air;cr}}{V_{cap} + V_{air;tot}} \tag{8}$$

where

V_{cap} is volume of all capillary pores (and other water filled pores smaller than capillary pores),

$V_{air;tot}$ total volume of air pores,

$V_{air;cr}$ critical volume of (water filled) air pores.

The size distribution of air pores is specially considered also in the filling of air pores by water i.e. when evaluating the active water saturation of concrete. The propagation of frost attack is assumed to take place according the following Equation:

$$RDM = 1 - \frac{E_N}{E_0} = K_N \cdot (S - S_{cr}) \quad (9)$$

where

RDM is	degree of damage (relative dynamic modulus) (*0 ≤ RDM ≤ 1*)
N	number of critical freezing events,
S	active degree of saturation at the moment of freezing,
S_{cr}	critical degree of saturation,
K_N	coefficient of degradation.

The coefficient of degradation can be determined from the formula:

$$K_N = \frac{A \cdot N^C}{B + N} \quad (10)$$

where A, B and C are constants.

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.

Carbonation and corrosion of reinforcement are evaluated taking into account the momentary temperature and moisture conditions in concrete. The rate of carbonation increases when the moisture content in concrete is lowered. Both carbonation and corrosion rate increase with higher temperature. The effect of frost attack on the rate of carbonation is considered.

The following equation is used for evaluating the dependency of carbonation coefficient on relative humidity and temperature (Vesikari 1999):

$$k_{ca} = k_{ca,0} \cdot (3.221 - 3{,}172 \cdot \phi)^{0{,}5} \cdot (T/293)^{0{,}875} \quad (11)$$

where

k_{ca} is coefficient of carbonation, $mm/a^{0.5}$

$k_{ca,0}$ is coefficient of carbonation at temperature 293 K and relative humidity 70%, $mm/a^{0.5}$.

When concrete is exposed to internal frost attack, the carbonation coefficient increases with the increasing internal damage in concrete. In that case the total carbonation depth is determined as the sum of incremental carbonation depths which are determined from Eq. (5). The carbonation coefficient k_{ca} increases with time with increasing frost deterioration in concrete (Vesikari & Ferreira 2011):

$$x_{ca} = \sum \Delta x_{ca} \tag{12}$$

$$\Delta x = \frac{\left(k_{ca} \cdot (1 + 0.64 \cdot (1 - RDM)^{1.32}\right)^2}{x_{ca}} \cdot \Delta t \tag{13}$$

The depth of corrosion is determined as follows:

$$s = \sum \Delta s \tag{14}$$

$$\Delta s = c_T \cdot \frac{41 \cdot \left(1 - 0.29 \frac{pbs}{100}\right) \cdot \phi^{1.67}}{2 \cdot s} \cdot \Delta t \quad \textit{when } \phi \leq 0.95$$
$$\textit{and}$$
$$\Delta s = c_T \cdot 15 \cdot \Delta t \quad \textit{when } 0.95 \leq \phi \leq 1.00 \tag{15}$$

s is	the depth of corroded steel, μm
t	time, years
pbs	portion of blast furnace slag of total weight of binding agent, %
φ	relative humidity
cT	correction factor for temperature.

Correction factor for temperature is determined as:

$$c_T = 1.6 \cdot 10^{-7} \cdot (30 + T)^4 \tag{16}$$

where T is temperature, °C.

There are two limit states for corrosion used:
Serviceability limit state, which is used when the structure is visible:

$$s_{ls;s} = 100\,\mu m \cdot \frac{c}{d} \cdot (1 - RDM) \tag{17}$$

where
c is concrete cover, mm
d diameter of reinforcement, mm
and, ultimate limit state which is used when the structure is not visible

$$s_{ls;u} = \frac{d}{5} \tag{18}$$

3.5.11 Corrosion of metals

Metals and metal coatings in building constructions are exposed to atmospheric corrosion, when their surface is wetted. The ISO standard 9223 on classification of corrosion of metals defines the time of wetness as number of hour per year when the structure is exposed to RH > 80% and T > 0 °C at the same time, see Table 24. The metal used in the constructions should therefore fulfil the requirements for the given corrosion class according to the calculated time of wetness.

Table 24. Criteria for corrosion classes of metals based on time of wetness according to ISO 9223.

Corrosion class	Typical condition for structures found in	Used categories for Time of wetness
τ1		**< 10**
τ2		**10–250**
τ3	Outdoors in cold and dry climates	**250–2500**
τ4	Outdoors in all other climates	**2500–5500**
τ5	Outdoors in humid climates	**> 5500**

3.5.12 Indoor air quality and comfort

The indoor air quality and comfort are mainly the result of the whole building performance. Hence, there are couple of factors that are directly connected to the exterior wall constructions: thermal symmetry and non-presence of mould on the interior surfaces. Yet another factor dealing directly with the indoor air quality is the possible effect of the interior surface material of the wall construction on the control of indoor air humidity by potential buffering capacity.

The following table shows relevant factors for the hygrothermal performance of the exterior walls concerning indoor environment. The radiant asymmetry criteria are added from CR 1752.

Table 25. Indoor environment: Target values relevant for evaluation of the exterior walls.

Assessment/ Factor	**Thermal environment**	**Dampness and mould**
Good	According to Class 1 or PPD < 6% (radiant asymmetry: cool wall ΔT < 10 °C)	No detectable mould damage
Moderate	According to class 2 or PPD <10% (radiant asymmetry: cool wall ΔT < 13 °C)	Occasional condensation occurs. Minor areas of organic growth not exposed to indoor air of rooms for longer occupancy.
Bad	Not meeting criteria of class 2. PPD > 10% (radiant asymmetry: cool wall ΔT > 13 °C)	Regular condensation, organic materials exposed to RH > 80% for extensive periods, visible mould growth exposed (directly indirectly to occupied spaces)
Reference	EN 15251 Annex A/CR 1752	WHO (2009)

The indoor criteria for thermal comfort are mostly connected to the whole building performance and can only be predicted with whole building simulations (see next chapter). However, the inner surface temperature of the wall can be predicted with the (hygro)thermal simulations of constructions and the temperature difference can be calculated and evaluated.

The criteria regarding mould and dampness are closely connected to the assessment of moisture performance and durability described in the previous chapters.

Appendix D describes the assessment guidelines and gives a procedure for the calculation with an assessment example.

3.5.13 Summary of the building physical assessment

The present description of the simulation and assessment of the hygrothermal performance of exterior wall constructions is summarized in the graphical presentation in Figure 33.

It is assumed that the construction solutions to be assessed with the hygrothermal simulations are already assessed and optimised by the other assessment criteria for sustainable refurbishment in the SUSREF project.

This presentation illustrates the iterative nature of the process. Even though not every action is given, the illustration gives an overview of the components included in the assessment.

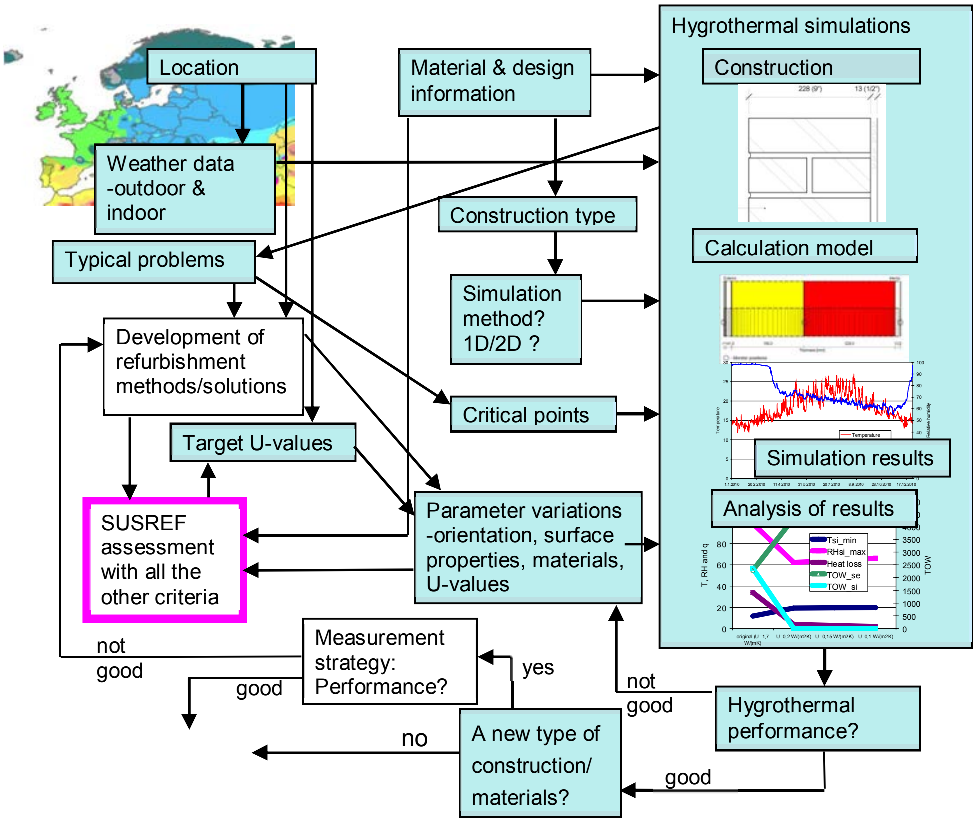


Figure 33. Flow chart presentation of the hygrothermal analysis – with a connection to the overall assessment method applied in the SUSREF project.

3.5.14 Conclusions

In this Chapter, a systematic approach was presented how to use the state-of-art knowledge and simulation tools we have today in order to analyse the building physical performance of building envelope constructions that already are optimised in terms of energy efficiency and sustainability.

However, to meet the needs of the building designers in their work with the refurbishment projects in practice and in order to insure the performance of these solutions, this chapter focused on the guidelines for a relatively simple and fast engineering method. This includes recommendation of calculation tools that most of designers can be expected to have access to. More advanced – and expensive – tools are recommended for research purposes in order to understand the phenomena as far as possible. Simpler tools and methods – in right hands – however, are often sufficient enough to analyse most of the real life problems.

The building physics modelling was here understood as the analysis on the constructions only. The building physical assessment has an important role in the overall technical assessment of the suitability of the refurbishment concepts. It ensures the physical performance and durability of the structures in the same time that the energy and material use related environmental effects are minimised. With the methodology given in this report it is possible to test how far we can go with improving the energy performance without causing problems in terms of other criteria.

3.6 Assessment of energy performance on building level

3.6.1 Introduction

There are different tools or ways to address buildings energy performance, indoor air quality conditions and construction quality. Depending on the required detail level of the data, tools at building level could be enough but with issues related, for example, to cold bridges, zones exposed to high humidity, poorly ventilated areas, corners... – special attention should be paid, and will require more detailed studies that take into account the special boundary conditions that occur near these points.

The methods to calculate energy performance or indoor air quality at building level can be classified as steady state methods or dynamic methods

- Quasi-steady-state methods are those that calculate the heat balance over a sufficiently long time (typically one month or a whole season) using daily or monthly mean average temperatures, and which enable to take dynamic effects into account by an empirically determined gain ad/or loss utilization factor. Standards fall under this category.

- Dynamic methods, are those that calculate the heat balance with short times steps (typically one hour) taking into account the heat stored in and released from the mass of the building.

3.6.2 Standards

Standards related to energy performance set the basis or the methodology to characterize the thermal performance of building correctly and define the required boundary conditions.

The main standards that present methods for thermal energy performance are EN 832 – C*alculation of energy use for heating – residential buildings* and ISO 13790: *Energy performance of buildings – calculation of energy use for space heating and cooling*.

Both of them present quasi steady-state methods for the estimation of heating and cooling energy consumption.

EN 832: Thermal performance of buildings – Calculation of energy use for heating – residential buildings:

This standard provides a simplified calculation method for assessment of heat use and energy needed for space heating of a residential building. It is not developed a specific method for cooling, and doesn't consider air quality.

The use of the tool is recommended in cases when a rough idea of the whole building heating energy demand before and after the refurbishment is needed.

However, monthly heating demands predicted by this tool may differ substantially from actual demands, especially in the beginning and end of season: It is not a tool for system dimensioning; no issues related to indoor air relative humidity are addressed.

The standard is based on steady state energy balance, but takes into account monthly or stationary external temperature variation, indoor temperature set point, the dynamic effect of solar and internal gains, and transmission and ventilation losses. It is based on energy transfer, but neither moisture transfer nor latent heat is considered.

The standard only applies to residential buildings.

The building heating demand is a relationship between heat losses (transmission and ventilation), heat gains (internal and solar) and a reduction factor for the heat gain, to allow for the dynamic behaviour of the building.

The calculation method is based on the following equations:

$$Q_h = Q_{loss} - \eta\, Q_{gains} \tag{19}$$

Where

Q_h is the building energy need for continuous heating,

Q_{loss} is the total heat transfer losses (transmission and ventilation)

Q_{gains} accounts for heat gain (internal and solar).

$\eta_{H,gn}$ is the dimensionless gain utilization factor.

Where heat loss at constant internal temperature it is calculated by the following equation:

$$Q_{loss} = (H_T + Hv) \bullet (\theta i - \theta e) \bullet t \tag{20}$$

θ_i = is the internal set-point temperature
θ_e = is the average external temperature during the calculation period:
t is the length of the calculation period
H_T is the heat loss transmission coefficient, through the envelope elements, calculated by the relation

$$H_T = \sum A_i U_i + \sum l_k \psi_k + \sum x_j \tag{21}$$

Where:
A_i is the area of element i of the building envelope, (m^2)
U_i is the thermal transmittance of element i of the building envelope, expressed in (W/Km^2);
l_k is the length of linear thermal bridge *k*, (m)
Ψ_k is the linear thermal transmittance of thermal bridge k, expressed in (W/Km)
Xj is the point thermal transmittance of point thermal bridge *j*,
H_V is the ventilation loss coefficient. That is calculated by

$$H_v =, \dot{V} \rho_a C_a \tag{22}$$

where:
$\dot{V}$ is the air flow rate through the building; related with air change rate (n) and conditioned space volume (V), $\dot{V}$ = nV
$\rho_a C_a$ is the heat capacity of the air per volume. 0.34 Wh/m^3K.

Where heat gains, are calculated, summing up the internal gains (Q_g) and solar gains (Q_S). $Q_{g=} Q_i + Q_s$.

Internal gains (Q_i) result from the metabolic gains from occupants, power consumptions of appliances and lighting devices…)

Solar gains result from the local sunshine irradiation (I) and the solar transmission (SHGC of glasses, transparent covering, transparent insulation….) and absorption characteristics of the collecting areas – i.e, walls behind transparent covering.

Solar irradiation is available from meteorological data, and transmission and absorption are properties inherent to materials.

Internal gains can be calculated from the power of appliances and internal loads.

ISO 13790: Energy performance of buildings - calculation of energy use for space heating and cooling:

Compared to Standard EN 832, ISO 13790 applies to residential and tertiary buildings.

Like EN 832, this standard deploys a steady state energy balance algorithms to estimate space heating demands for buildings, and it uses a mirror image of the approach for heating for cooling loads.

As with EN 832, the monthly calculation gives correct results on annual basis, but the results for individual months close to the beginning and the end of heating and cooling season can have large relative errors.

In addition, ISO 13790 allows more detailed specifications than EN 832, allowing the introduction of schedules with different set point, ventilation rates, internal heat gains, moisture generation.

An alternative simple method for hourly calculations has been added to facilitate the calculation using hourly user schedules (such as temperature set-points, ventilation modes, operation schedule of movable solar shading and/or hourly control options based on outdoor or indoor climatic conditions). This method produces hourly results, but the results for individual hours are not validated and individual hourly values can have large relative errors.

3.6.3 Dynamic simulation tools and methods

Dynamic thermo-energetic methods are based on temporal evolution of different points of the building due to dynamic excitations (i.e weather and building use related). The complexity of solving temporal/spatial equations, has led to the development of several simulation software programmes (i.e EnergyPlus, TRNSYS, IDA-ICE….)

Compared to quasi-steady state methods, results are generally more precise, allow data analysis for shorter period of time ,i.e. monthly, weekly, daily or on hourly basis and allow the estimation of peak power demand in order to dimension an HVAC system.

However, complex calculations – on the other hand - require very precise and extensive input data. Special attention should be paid to defining boundary conditions and the building itself. (For further detail, please refer to ISO 13790)

Some of the well-known building energy simulation software, like EnergyPlus and TRNSYS are able to simulate the energy flows in a building in dynamic conditions, and are mainly situated at the intermediate level of "granularity." All the models also calculate the moisture level in the indoor air and can account for moisture storage in hygroscopic material. Though water vapour exchange between room air and surrounding material (walls and furniture) is governed by three physical processes (transfer of water vapour between the air and the material surface, the moisture transfer within the material and the moisture storage within the material), not all phenomena are always considered in simulation tools.

Nowadays different numerical models are available to describe the transient water vapour balance of a room and predict indoor air humidity. A typical room moisture balance includes water vapour production by moisture sources (humans, plants), convective water vapour transfer with infiltration and ventilation air, and water vapour exchange with the building fabric and furniture.

Energy plus with HAMT and CTF:

EnergyPlus is a powerfull whole building energy model that considers both energy and moisture, (moisture sorption by building materials) and ventilation which allows natural ventilation and mechanical system to interact more fully.

Depending on the required data output, i.e energy consumption or energy consumption, indoor air RH, and envelope's material water content, two main different algorithm may be used:

- **CTF:** Conduction Transfer Function – CTF – Conduction transfer functions are an efficient method to compute building **energy demand**. The zone heat gains consist of specified internal heat gains, air exchange between zones, air exchange with the outside environment, and convective heat transfer from the zone surfaces. However, conduction transfer function series become progressively more unstable. (EnergyPlus Engineering reference).
- **HAMT**: The combined heat and moisture transfer finite (HAMT) solution algorithm is a completely coupled, one-dimensional, finite element, **heat and moisture transfer** model simulating the movement and storage of heat and moisture in surfaces simultaneously from and to both the internal and external environments. It also simulates the effects of moisture buffering,

  HAMT is also able to provide temperature and moisture profiles through composite building walls, and help to identify surfaces with high surface humidity.

The level of the input data required and the computational time are increased considerably from one to the other. Because ~~of~~ the diffusion of the water in construction materials is slow process, it requires more than 5 year simulation period before results stabilize, which lead to higher computational times. Once the system is stabilized, it has been observed that both heating and cooling demands calculated with HAMT are lower than those calculated with CTF. In HAMT calculations the façade water content mass is taken into account, consequently walls have more thermal inertia and worse conductivity, but in any case, it is expected that thermal inertia prevails, which reduces the calculated energy consumption.

IDA indoor Climate and Energy (IDA ICE) is another tool for the simulation of energy consumption, indoor air quality and thermal comfort.

4 Refurbishment concepts – study of literature

4.1 Introduction

This chapter presents an overview of refurbishment technologies based on literature review. It focuses on additional thermal insulation of external walls. The study does not deal with any other building components and systems.

The main goal is to give a comprehensive view of the different technologies available for refurbishing external walls. The scope of the study is to collect information about the refurbishment of residential buildings, but the results and technologies presented here may also be applied to other building types.

4.2 Technologies for replacing refurbishment of existing walls

Technologies for replacing existing walls or parts of them are large-scale renovations. If the walls to be replaced are non-load-bearing, they may be completely replaced in some cases. Especially certain walls of high-rise buildings, or parts of walls in residential blocks of flats may be suitable for complete replacement.

In the case of load-bearing walls, only the existing façade and insulation layer are usually removed and the inner load-bearing layer is left in place.

Replacing refurbishment technologies may be the only means of refurbishment if insulation layer has excessive microbe growth or the façade or its anchoring has massive structural damage. Replacing technologies may also be used if an especially long service life is wanted or if the wall would become too thick with additional external thermal insulation.

Replacing refurbishment technologies give a lot of freedom in selection of the new wall structure. If non-load-bearing walls of a building are completely removed, the new wall structure can be chosen freely. In case of load-bearing walls, all the methods presented in the section *"technologies for applying external thermal insulation layers"* can be used for new external layer, once the existing façade and insulation are removed.

4.3 External thermal insulation layers

External insulation is usually the preferred method for adding insulation to existing buildings. It does not cause loss of interior space and it is possible to be installed while the building is in use. It also makes it possible to address thermal bridges and moisture problems in a comprehensive way.

Additional external insulation can have a significant impact on mitigating the thermal losses of a wall, diminishing the effects of existing thermal bridges and improving the air tightness of a wall. (Groleau et al. 2007)

The additional insulation and new cladding are usually fixed straight to the load-bearing system of the existing walls, but some degree of removal of external construction, e.g. external siding, may also be needed.

However, in some cases, the external thermal insulation might be hard to implement, since it alters the visual appearance of the building. This might be the case especially on the "street side"-facades of buildings in urban areas (IEA 2010) or in historical buildings. External thermal insulation causes also challenges, since eaves, verges and details around windows often need to be altered. (EST 2005)

Thermal bridges in external thermal insulation

External thermal insulation can guarantee the continuity of the insulation and reduce the number of thermal bridges in the external wall. (IEA 2010) However, removing all the thermal bridges during a renovation can be a complicated and laborious task. The following figure shows some typical thermal bridge problems for external thermal insulation and possible corrective measures for each of the problems. (IEA 2010)

Air tightness in external thermal insulation

Poor air tightness of external wall causes unwanted air infiltration through the walls, which increases energy losses and can create a risk of condensation inside the wall.

One typical source for air leakage is the connections between the external wall and windows and doors. These connections can be re-sealed when installing external insulation. Other sources of unwanted air-leakage are cracks and fissures in the enclosing surfaces and porous materials used in walls. (IEA 2010)

Porous materials, such as bricks, concrete, or mineral wool, which are permeable to air are often used in wall structures. If these materials are not protected with an airtight layer, such as coated plasterboard, or paint, then the air can flow through the structures causing thermal losses. (IEA 2010)

Different concepts for applying external thermal insulation layers

External thermal insulation means thermal insulation, which is installed on the outer surface of an external wall. These systems can be implemented in most cases directly on top of the existing structure. However, in some cases it might be necessary to remove the cladding and existing thermal insulation before applying.

This study divides the external thermal insulation into four different categories, which are

- External thermal insulation composite systems (ETICS)
- Ventilated façades
- External thermal insulation panel systems
- Insulating plasters.

External thermal insulation composite systems

External thermal insulation composite systems consist of insulating material, reinforcement layer and a finishing layer. The insulation layer is attached to the wall either by an adhesive or by both adhesive and mechanical fixings. The top layers with rendering, reinforcement and surface treatment are applied directly on the insulation layer without any air cavities in between.

In various parts of the Europe, these systems are called '*external thermal insulation composite systems' (ETICS)*. Also other names exist, since in Ireland and United Kingdom term '*external wall insulation systems'* and in United States and Canada '*exterior insulation and finish systems*' (EIFS) are used. On the other hand, the abbreviation EIFS also translates to 'external insulation of *façades*' or *'Externally Insulated Façade System'* in Central Europe, both of which mean same system. (Künzel et al. 2006, Trpevski 2007)

External thermal insulation composite systems (ETICS) are the most common methods of improving the thermal protection of external wall structures in Europe. It is the most popular thermal insulation system in countries such as Germany, Poland, Italy, Netherlands and Portugal (Wetzel and Vogdt 2007, Plewako et al. 2007, Brunoro 2007, Ravesloot 2007, Bragança et al. 2007).

The insulating material of ETICS is typically polystyrene or mineral wool, which is attached to the existing structure either by bonding, mechanical fixings or a combination of these two. Also rail mounted systems can be used as they are applicable if the surface is unfavourable for the other options. (Wetzel & Vogdt 2007)

Ventilated façades

In many European countries, such as Portugal and Italy, ventilated façade is the most common façade renovation solution after the ETICS. The ventilated façade consists of thermal insulation and an external cladding. The system is dry-mounted, in other words, all the fixings are made with mechanical connections, such as screws and bolts.

The shape of the cladding can vary from slabs to panels and ceramic tiles, while the surface material can vary between stone, brick, ceramics, concrete, metal, plastic and wood. (Brunoro 2007)

Ventilated façade can be applied to both solid and fraØe walls. It can be applied to various different frames and the supporting frame can be made either from steel, aluminium or wood.

External thermal insulation panel systems

External thermal insulation panel systems consist of insulating material inside a façade panel. The panels are made of metal (i.e. aluminium or steel) and filled with a thermal insulation, such as EPS or mineral wool. Panel systems are used, for example, in France in approximately 10% of façade renovations. (Groleau 2007)

The panel systems can be attached to a new, lightweight supporting frame that is fixed to the existing wall. On the other hand, the panels can also be fitted to an existing structural frame where original panel system needs to be replaced. (TATA)

One of the benefits of panel insulation is that the panels can be relatively large (up to 12 m long), which speeds up the installation.

Insulating plasters

Insulating plasters are a form of insulation, where the insulating material is sprayed straight onto the existing wall structure.

The benefits of these systems is that they can help fix irregularities and defects in the existing wall and can be easily applied to irregular or complicated facades. They do not need additional adhesive for fixing.

In one example system the insulation material is a lightweight insulation plaster, which is made of polystyrene (PS) beads mixed with plaster. The plaster is prepared on site with a plastering machine and sprayed on the wall in multiple layers. The surface layer is leveled and a coating layer is applied on top of it. The coating layer is then finished with paint.

4.4 Internal thermal insulation of the envelope

The main factor affecting the efficiency of internal insulation is the available space for insulation, because insulation thickness relates closely to its performance.

Internal insulation has a lot to gain from high-performance insulation materials, since the insulation thickness is often limited. Materials like polyurethane (PU) and phenolic foam (PF) can give higher U-values than mineral fibre or cellulose insulation with same insulation thicknesses. (Energy Saving Trust 2005)

The internal thermal insulation lacks the weather cover that protects the existing structures on external insulation systems. It can also add the stress of outer surface of the wall by lowering the temperature of the external walls. When influence of indoor climate is diminished, the freezing temperatures are more likely on the façade. (IEA 2010)

Risk of condensation

Additional internal insulation creates a barrier between the existing wall and the indoor climate when installed, preventing the wall from warming up. Due to this the structures' dew point (the temperature in which the water vapour condensates) shifts inside. In order to prevent water vapour from condensing between existing wall and the insulation, the least permeable materials should be placed on the warm side of the insulation and a water vapour barrier should be placed between the insulation and the interior finishing. (IEA 2010)

Thermal bridges and air tightness in internal thermal insulation

The insulation and vapour barrier should be seamless to avoid the risk of condensation. This is important especially at the junctures i.e. between walls and between walls and ceilings. However, this might prove difficult and require detailed studies for the junction points. (IEA 2010)

Different concepts for applying internal thermal insulation

Internal thermal insulation concepts can be divided into two main types based on the fixing method of the insulation. The insulation can be fixed either to the existing structure or to a freestanding studwork.

Insulation systems which are discussed here are:

- plasterboard laminates fixed to the existing wall
- insulation boards fixed to the wall with timber battens and covered with plasterboard
- insulation boards fixed to the wall and plastered directly
- Insulation fixed to a freestanding studwork.

Plasterboard laminates

Plasterboard laminates are widely used and easy to install. The available products' insulation thicknesses might cause a problem, if very high improvements in thermal insulation are targeted. (EST 2005)

As an example, one manufacturers' plasterboard laminate product range includes thicknesses from 30 to 90 mm. With a plasterboard thickness of 10 mm, this gives insulation thicknesses from 20 to 80 mm.

Insulation boards covered with plasterboard

The difference between this system and the plasterboard laminates is that the system components are installed separately. The installation is not as fast, but the benefits are lower cost and that the insulation thickness can be chosen freely.

Insulation boards fixed to wall and plastered directly

Insulating wall internally with directly plastered insulation boards is quite similar to the ETICS-system. However, this system is lighter, as there is no need for anchoring of the boards. Compared to the previous two systems, chamfered corners are easier to make with this system.

The insulation work starts with rendering the wall with cement or lime slurry and then rubbing the insulation boards into place to avoid air pockets. The top coat consists of two coats of base coat plaster. (EST 2005)

Insulation fixed to a freestanding studwork

Freestanding studwork gives the possibility to leave an empty air cavity behind the additional thermal insulation layer. This cavity might be needed for ventilation, if it is suspected that moisture can penetrate the outer wall structure. The disadvantage of this kind of ventilated structure is that it takes even more of the limited space that is available for installing the internal insulation than the other solutions.

Freestanding studwork can be made from steel or wood. The benefit of steel studwork is the faster installation speed. However, due to higher thermal conductivity of steel, the steel studwork can cause significant thermal bridges. (EST 2005)

According to EST (2005) a 100 mm steel studwork wall can achieve U-value of less than 0.31 W/m^{2}K if thermal bridges are not concerned, giving it a better U-value than that of a similar wood studwork wall (0.39 W/m^{2}K). However, when the thermal bridges are taken into account, the U-value for a steel studwork wall rises to 0.54 W/m^{2}K. (EST 2005)

4.5 Cavity insulation

Cavity insulation is a simple way of insulating cavity walls during renovation. It is a popular method of additional insulation in countries, where cavity walls are common. It is widely used i.e. in the Netherlands, where cavity insulation is the most popular insulation system after ETICS. (Ravesloot 2007)

The most common way is bulk material insulation, where the cavity is filled by blowing a bulk of insulating material into the wall cavity. Also foam injection techniques exist, but they are not as commonly used due to the more advanced installation process (IEA 2010). The occupants can remain in the building while the cavity insulation is installed. This way it causes only minimal disturbance. (EST 2007)

Thermal bridges and humidity

Cavity insulation may not be effective in all the cases, due to the thermal bridges between the two wall wythes. This might be the case with old cavity walls where the wythes may be linked together with such a many connecting bricks that additional internal insulation becomes profitless. Therefore, the size and type of thermal bridges needs to be inspected when planning renovation by filling the cavity (IEA 2010).

When the cavity is filled with insulating material, the transportation of humidity out of the masonry must be ensured (Ravesloot 2007). The insulation material itself must not be capillary or hydrophilic and it must also be permeable to water vapour (IEA 2010).

Insulating with foam

Foam injection techniques are not as commonly used today as bulk material insulation, since they require precise measuring of the filling and foam's expansion to avoid the facing to be pushed out of shape by too much pressure (IEA 2010).

This is mostly due to the installation process, which requires more advanced methods than the bulk insulation technique. While insulating the cavity, the filling of the cavity and the foam's expansion needs to be measured in order to avoid deformations on the façade due to excessive pressure.

4.6 Combined wall insulations

In some cases, a combination of different refurbishment technologies may be justified. However, in most of the cases, the use of a single system is usually a better solution. Some possible combinations of external, internal and cavity insulation are discussed in the following.

Internal insulation + External insulation

In general, combining internal and external insulation technologies does not bring much benefits compared to the scenario, where either the internal or external wall can be insulated. If, for example, external insulation can be applied, it is more reasonable to add insulation thickness to the external insulation layer than add another insulation layer on the internal side of the wall. However, in some cases both internal and external insulation may be used in different parts of a building. This might be the case in urban environments, when the front façade needs to be insulated internally (to avoid changes in the appearance of the façade) and the back façade can be insulated externally (IEA 2010).

To ensure the functioning of mixed insulation, thermal bridges need to be minimised. The places where wall insulated from outside meets a wall insulated from the inside should also have overlapping insulation (both internal and external insulation) (IEA 2010).

Internal insulation + Cavity insulation

In some cases, when the façade of a building may not be altered, but a highly efficient additional thermal insulation is needed, combining cavity insulation with internal insulation might be a viable option. By insulating the cavity, the insulation thickness of the inner insulation layer can be reduced. However, this method is not commonly used (EST 2005).

External insulation + Cavity insulation

Combining external insulation with cavity insulation may be used in some cases. When cavity is insulated and thermal insulation is applied also externally, the thickness of external insulation layer can be reduced to gain the same U-value. (EST 2005)

On the other hand, a thin external insulation layer can be added to enhance the insulating capability of cavity insulation, and to protect the outer wall from rain penetration problems. (EST 2005)

4.7 Advanced refurbishment technologies

This chapter will discuss advanced refurbishment technologies. Some of these technologies are already commercially available, but they haven't been adopted to wider use. On the other hand, some technologies are still in development phase and some are only discussed at a theoretical level.

Phase-changing materials (PCM's)

Phase change materials, or PCM's help to utilize the so-called latent heat. The latent heat is energy which released or absorbed during the phase change of a substance. Latent heat can be absorbed or released, for example, when a substance changes phase from solid to liquid form. (Knaack et al. 2007)

One example of a PCM is a material by BASF. The Micronal PCM is a microencapsulated latent heat storer, which can be used with many existing construction materials, such as gypsum, plaster and concrete. The following image shows how the PCM microcapsules are integrated in a construction material.

The latent heat of PCM's can be used for two purposes in building applications. These are: use for heat control and use as heat or cold storage.

Gypsum plasterboards are widely used in lightweight buildings. Incorporating PCM into gypsum plasterboards enables increasing the thermal mass of light buildings (Mehling & Cabeza 2008).

PCM-plasterboards may offer a wide range of potential uses in external wall refurbishment. One possible use could be replacing concrete curtain walls with light wooden structures and PCM-plasterboard without losing the thermal mass of the wall. Installing PCM-boards to the inner walls could also help to lower the overheating in summer in old buildings without cooling, or in passive-level renovations where might be a risk of overheating in the summer.

The PCM-plasterboards with microencapsulated paraffin match all the handling and installation requirements of regular plasterboards. This enables these boards to be installed using existing techniques and processes. (Mehling & Cabeza 2008)

Knauf and BASF have developed a commercial product, which is called Knauf PCM SmartBoard. By installing two 15mm boards, the heat capacity of a light wall is comparable to a 14cm concrete wall or 36cm thick brick wall. (BASF 2011)

Another option to integrate microencapsulated PCM into building materials is the integration of PCM into wall plaster. (Mehling & Cabeza 2008)

Plasters with microencapsulated paraffin have similar thermal mass properties as gypsum boards and they can be used as conventional plasters. They can be used to replace conventional plasters in internal thermal insulation systems.

The heat-storing capacity of a PCM-plaster can be varied by changing the thickness of the plaster. (BASF 2011).

An example of a commercially available PCM-application is the GLASSX crystal. The core of this system is a PCM salt hydrate, which is used as the storage material. Salt hydrate stores the solar radiation energy and releases it later as radiant heat. System has also overheating protection with the help of prismatic glass. The prismatic glass blocks the solar radiation in summer (at angles more than 40°) and allows the radiation to pass through in the winter.

Vacuum-insulation panels

Vacuum insulation panels (VIPs) have a thermal resistance about a factor of 10 higher than that of equally thick conventional polystyrene boards. These systems make use of 'vacuum' to suppress the heat transfer via gaseous conduction.

VIP boards consist of micro-porous core structure, which is vacuum-packed in a gas and moisture tight barrier envelope. Fumed silica powder is the main core component for VIP's. The biggest benefit of silica powders is that, once compressed, the pore size between silica particles is below the mean free path of atmospheric gas molecules at pressures of 1–10 mbar. This way the convection in the insulation material is minimized and limited to conduction and radiation.

VIP's weak part is the barrier film, which needs protection, not only during construction, but through the lifespan of the building. Best way to protect VIP's is to encase them inside protecting EPS-covering.

Vacuum-insulation panels offer a large potential in internal insulation, since the insulation thickness is often limited. Since VIP's have a superior insulating capacity compared to traditional insulation materials, they can offer better insulation when used in internal insulation.

Green walls

Green walls have mainly aesthetic benefits compared to other refurbishment methods. Some of them may also bring benefits in heating and cooling energy demand by offering shading, wind protection and additional thermal insulation for the wall.

Well placed plantations can offer real protection from the sun in the summer and let the solar radiation through in the winter. Some plantations can also offer wind protection, especially if placed in front of openings. (IEA 2010)

Spots green suspended walls can be installed on most of the wall surfaces. In this system pre-vegetated panes or fabric system is fixed to an existing wall structure or a supporting frame. The greatest benefit of this green wall type is aesthetic and, since it has only minimal effect on heating or cooling energy demand of a building. (Almusaed 2011)

Höweler+Yoon architects have installed such a wall system in Boston, Massachuttes. The system consists of felt panels hanging from stainless steel cables.

According to Almusaed (2011) another type of green walls are compact green suspended walls. The main difference between this type and the "spots"-type is the coverage of the green cladding. The structural systems are basically the same, but the green wall covers most of the façade.

This type of green wall has some benefits on heating or cooling energy demand. In summer, the vegetation shades the façade and cools down the wall surface. In addition, evaporation and transpiration can also add to the cooling effect of the wall. In winter, this wall type can reduce convective heat losses by creating a a layer of air between the wall and the environment. This is the case especially when using evergreen plants. (Valesan & Sattler 2008)

Living walls system

The living walls system is not integral part of the façade, but it gives some green covering for the façade instead. In this system, the green façade is created by putting, for example, plantation boxes in open spaces, such as balconies. The benefits of this green wall system are mainly aesthetic, but it can also reduce wind speeds on facades and give shade in summer. (Almusead 2011)

Living walls system is not an actual refurbishment method and it should be considered only as an additional feature on the facade. It might be applicable during façade refurbishment if proper open spaces already exist in the building.

Climatic skin layer

The climatic skin layer is an integral part of the external wall. Walls with climatic skin layer consist of internal (load-bearing or non-load-bearing) layer, insulation layer and the climatic skin layer. This system is more complex than the other systems, since it includes an irrigation system for the vegetation. (Almusaed 2011) Climatic skin layer gives weather protection for the insulation layer and it also gives the visual outlook for the building.

An example system consists of an aluminium frame, where hydroponic medium and pressurized irrigation pipes are integrated into the frame. The frame has holes at the top and bottom edges, to allow the water to pass from panel to another.

Climatic skin layers could be used with replacing renovation methods, where the outer layers of existing façade are removed. This way, existing facades could be removed and replaced by green facades.

Evaporative wall

Evaporative wall is a concept, which aims in reductions in the summer air conditioning energy consumption by using the latent heat of evaporative water to cool down structures. (Naticcia et al. 2010) Evaporative walls can be used for reducing summer temperatures and the risk of over-heating in buildings.

Evaporative wall has the same basic structure as ventilated façades, but it is also equipped with water-evaporative system. The water-evaporative system exploits the latent heat of water evaporation to absorb summer cooling loads. It requires insertion of a water spraying system and a proper insulating layer in the ventilated air cavity. The insulation layer acts as an insulation and a porous water storage. (Naticcia et al. 2010)

One potential use for the evaporative wall is that it could be used in creating more effective ventilated façades. Evaporative wall could allow thicker insulation layers, without the risk of overheating in summer. This way, evaporative wall structure could lead to reduced heating energy need in winter and reduced cooling energy need in summer.

Photovoltaic façades

Photovoltaic (PV) façades offer one of the most viable ways to produce electricity in urban environment. However, PV façades face problems, since neighboring buildings can form obstructions to sun and sky and reduce amount of available solar radiation. (Yun & Seemers 2009) Also temperature increase in PV modules creates problems, since high temperatures cause electrical output of PV modules to decrease. (Yun et al. 2006)

The amount of annual solar radiation also varies widely depending on the location of a building and the orientation of its façade.

The PV façades are multi-functional, and they are able to mediate heat, air and daylight transmission between inside and outside of a building in addition to producing electricity. Therefore, the simple calculation of estimating annual radiation on building envelopes is not sufficient for evaluating viability of PV façades, and integrated analyses are needed. (Yun & Seemers 2009)

Photovoltaic modules should not be designed in isolation from other building components, or considered plainly as an add-on to a normal wall, for this can give wrong conclusions on their effectiveness.

The most common design of photovoltaic façade is similar to ventilated facades. The main difference is that the “cladding” is done by PV elements, instead of normal construction materials. The air cavity helps to cool down the photovoltaic modules and to increase their efficiency. Commercial photovoltaic façade solutions are available.

The design of the PV façade can have significant effects on the energy consumption and environmental performance of a building and they should not be analyzed in isolation from other systems.

In theory, these systems have the same annual electricity output, since they have the same PV module area and they receive the same amount of annual solar radiation. If other effects of the PV panels are left out of considerations, these systems have virtually no difference.

However, a study by Yun et al. (2009) show that these two different concepts have significant differences in environmental and energy performance. According to their study, the single skin (PVSS) design is more efficient than the double skin (PVDS) design. For an office building they analyzed, the PVDS façade is estimated to consume 26% more energy than the PVDS design.

This is mainly due to increase in lighting and heating energy need that PVDS design causes. Due to the additional glazing, less light and solar energy can pass the façade, causing increased energy demand. PVDS consumes 30% more heating and 21% lighting energy than PVSS design. In addition, the heat trapped in the cavity space increases summer cooling energy need by 18% and decreases PV module output by 3%.

On the other hand, the air cavity of the double skin façade may have potential for heating and cooling purposes, making some PVDS designs viable. Yun et al. (2006) have presented a more complex version of PVDS, in which the air cavity is used as a pre-heating device in winter and a natural ventilation system in summer. This system can decrease the air temperature in the cavity in summer, thus decreasing cooling energy need of a building and increasing their electric output. (Yun et al. 2006)

When PV modules are used for building refurbishment, they should be designed simultaneously with the other façade elements and building components. This is due to the multi-functionality of a PV façade. If PV modules are integrated into otherwise ready wall structure, an optimal wall structure cannot be achieved. This is because the PV modules affect also building's heating, cooling, and lighting needs, in addition to electricity production.

Pre-heating hot water with solar collectors

Solar collector systems and their efficiency are also susceptible to location of the building and orientation of the façades.

When planning renovations with solar collectors, the possible orientations of thermal collectors are limited. The orientation should be between southeast and southwest. Orientation focusing on east or west reduces the efficiency of the collectors by about 20%, compared to south facing systems. In addition, the slope of the collectors also affects the efficiency of the system. (IEA 2010)

In Central Europe's weather conditions, maximum annual solar radiation is received with a slope between 35 and 45 degrees. When façade-integrated collectors are used, the reduction in annual cumulative solar radiation is about 30%. (Matuska & Borivoi 2006)

Annual energy use for the hot water production can be reduced 50 to 60% in individual homes and 20 to 40% in collective housing by installing thermal solar collectors. This refurbishment option should be considered in the beginning of the design phase, since its design affects multiple building systems. (IEA 2010)

The solar collectors can be installed either on a roof or on a wall. The wall installations suffer from poorer installation angle than the roof installations. On the other hand, walls have usually more area for installing solar panels. (Matuska & Borivoi 2006)

The façade integrated vacuum collectors are separated from their surroundings by a transparent cover. Convective heat transport is prevented by a vacuum and a range of different vacuum geometries are available in the market. Most compact collectors are called compound parabolic concentrator mirrors (CPS) which are only 45 mm thick. (Eicker 2003)

The collectors of this system can be installed relatively easy as an "add-on" to an existing structure. However, the connections to other building systems require detailed planning and simulations for optimal performance.

Facade integrated collector panels present a different approach in building retrofit design. Façade collectors slightly improve the thermal protection of a building in winter, and do not raise indoor temperatures significantly in the summer. (Matuska & Borivoj 2006)

This system requires more detailed design of the façade, since its integrated into the wall structure itself.

The plaster layer conducts the heat to piping, which carries the heated fluid to a heat exchanger. According to IEA (1999) this system is not as effective as flat plate collectors and has only 75% of their efficiency.

This kind of system might be used, if the solar collector system is not to be visible on the façade. The surface can be made to look like normal rendering, although the façade needs to have a dark color.

Transparent insulation (TI) materials

Transparent insulation on external walls can use the incoming solar radiation better than conventional walls. They are suitable especially for renovating old buildings with massive, conducting walls. TI panes can be installed directly on the external wall, since TI can provide both thermal insulation and weather cover for the wall. (Eicker 2003)

TI materials that are usually made of polymethyl methacrylates (PMMA), polycarbonates (PC) or glass. The PMMA has high transmittance and UV stability, but due to its brittleness and poor fire-retardance (B3) it has to be bounded between glass elements.

Polycarbonates (PC) are mechanically more stable than PMMAs and they can be processed without glass covering. They have a better fire-retardance class (B1) but are not very UV-resistant. The covering plaster is an acryl adhesive mixed with 2.5–3 mm diameter glass balls and it can contain additional UV-absorbers. The price for PC is significantly lower than that of PMMAs, with costs around 150 €/m^2. (Eicker 2003)

Glass capillary TI's are more complicated to fabricate than those made of polymer. They offer more temperature and UV-resistance, but are not otherwise mechanically very stable. (Eicker 2003)

Applications of TI insulation – Solar wall heating with TI

The solar heat input by absorption of solar radiation at wall surfaces cannot be typically fully utilized due to free or forced convection. When transparent thermal insulation is added on top of a wall, the loss of heat can be reduced (b). Since transparent insulation transmits solar radiation, the heat can be absorbed on the wall surface and the insulation can reduce the heat losses to the outside air. Transparent insulation can lead to a net heat gain so that the wall can act as a low temperature heater (c). (Mehling & Cabeza 2008)

One of the simplest TI solutions is solar heating wall with transparent insulation. This wall has transparent insulation attached to a massive wall. The massive wall stores the heat and releases it later by acting as a low temperature heater.

The system can be applied on south-facing massive walls without existing insulation. This means that in many renovation cases, the outer layers of external wall would need to be removed before applying this system. (IEA 1999)

This kind of system can cause overheating in summer conditions. Without any shading, the maximum coverage of this type of wall is 30% of the south façade. If the surface area is limited, this limits the potential solar gains in the winter time. The system can be improved by using simple overhangs that block sunshine in the summer, but allow it to pass in the winter time. By using overhangs, the area covered with TI can be extended to 40% of the façade with the same heat load in summer. (IEA 1999)

Commercial systems are already available, which do not need additional overhangs. An example of this kind of system is Solar panel, which incorporates translucent capillary panels covered with a transparent glass render finish. The glass render helps to reflect the excessive sunlight in the summer, thus preventing overheating. (Sto 2011b)

Typical wall structures may lack the sufficient thermal mass required for storing the solar heat. Increasing thermal mass may also prove difficult with normal wall structures, since it would require significant wall thicknesses. Transparent insulation can help to remove thermal bridges. The end planes of concrete floors may be un-insulated and thus act as thermal bridges. Even if additional insulation is added to the outside wall, these end planes remain as a “weak spot”. Combining TI material with opaque insulation can help to deduce thermal losses by heat bridges. The combined insulation can deliver a more uniform temperature distribution in the floor slab and the external wall. (IEA 1999)

<u>Winter heating and summer cooling by glass façade (trombe wall)</u>

Glass façades for winter heating are often referred to as trombe walls. The basic trombe wall is a massive wall covered with an exterior glazing with an air cap in between the two elements. Massive wall stores the energy that the solar radiation brings through the glazing. Part of the energy is transferred to the room by air by convection through the wall. At the same time, low temperature room air enters the air cavity from a vent at the bottom of the wall. The air heats up in the cavity and enters the room again through a vent at the top of the wall.

Classic trombe wall design can be enhanced to be used for winter heating and summer cooling by adding dampers at the top and bottom of the exterior glazing. In the summer time the damper A and upper vent are closed and damper B and lower vent are open. This setting causes the buoyancy effect to push the heated air upwards and out of damper B while drawing air out or the room through the lower vent. (Chan et al. 2010)

In the winter the operating setting is the opposite. Damper B is closed while damper A and both of the vents are open. This setting allows cooler air to enter the cavity from damper A, heat up in the cavity and flow into the room air from the upper vent. Once cooled, the air will exit from the lower vent. (Chan et al. 2010)

Winter heating and cooling applications through trombe wall applications are more complex than some other renovation solutions, due to the adjustable vents and dampers.

Solar chimney façades

The purpose of a solar chimney is to create airflow through a building. The driving force is the density difference of air between the inlet and the outlet of the chimney. It can provide airflow for both heating and cooling. Its operation principle is very similar to that of trombe wall's. (Chan et al. 2010)

When the solar chimney is used for heating, the optimal structure is to place an air cavity of 50 to 60 mm between the second skin and the (100 mm thick) insulation. The structure is quite simple and even conventional contractors are be able to install this structure within reasonable cost limits. (IEA 1999)

Solar chimneys could be applied in many of the façade renovations, since it's basic structure is very close to that of normal ventilated façade.

5 Energy saving potential – literature review

5.1 Introduction

This chapter summarises the results of relevant literature about the environmental and economical significance of sustainable refurbishment in Europe. The literature survey focused on the following reports:

- Cost-Effective Climate Protection in the Building Stock of the New EU Member States. Beyond the EU Energy Performance of Buildings Directive. Report established by ECOFYS for EURIMA (Petersdorff et al. 2005)
- Mitigation of CO_2 Emissions from the EU-15 Building stock. Beyond the EU Directive on the Energy Performance of Buildings. Report established by ECOFYS for EURIMA (Petersdorff et al. 2006)
- Building Renovation and Modernisation in Europe: State of the art review. Final report (Itard et al. 2008)
- Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report (Eichhammer et al. 2009)
- Environmental Improvement Potentials of Residential Buildings (IMPRO-Building). JRC Scientific and technical reports (Nemry et al. 2008).

5.2 Summary of the study "Cost-effective climate protection in the Building stock of the new EU member states"

Petersdorff et al. (2005) have modelled and assessed the CO_2 and energy saving potential of the refurbishment of buildings in the EU15 and in the new EU member states. According to the EUROSTAT the building volume in Europe is (2002) as follows:

- EU-15 18 0000 million m^2
- New Member states (Estonia, Latvia, Lithuania, Slovakia, Slovenia, Czech Republic, Hungary, Malta, Cyprus) 2 400 million m^2
- EU-25 20 400 million m^2.

The assessment of potential energy and CO_2 savings was based on the simple assumption that the existing building envelops can be improved with help of significant additional insulation and the energy savings can be calculated on the basis of the following equation:

$\Delta E = HDH * \Delta U * 1/\eta$

ΔE (kWh/m^2a) Energy savings related to the surface area of the construction element

HDH (kKa/a) Heating degree hours

ΔU ($W7m^2K$) Difference of U values before and after retrofit

η Efficiency of heat generation and distribution.

The value of 4000 was used for heating degree days (in Kd/a) for Baltic countries, 3850 for Poland and 3400 for Slovenia, Slovakia, Czech Republic and Hungary.

The energy for heating demand was calculated according to the principles of European standard 832 (CEN EN 832 Thermal Performance of Buildings – Calculation of Energy Use for Heating – Residential Buildings). The influence of cooling was not taken into account.

Energy tariff values (2002) and rates for different energy carriers were assumed to be as follows:

Table 26. Energy tariff values (2002) and rates for different energy carriers (Petersdorff et al. 2005).

	Tariff (2002) (e/kWh)	Annual rate increase (%)	Average 2002 – 2032
Gas	0.025	1.5	0.032
Oil	0.036	1.5	0.046
Coal	0.017	1.5	0.022
Electricity	0.085	1.5	0.188
District heating	0.035	1.5	0.045
Wood	0.017	1.0	0.020

The calculation of the annual capital costs was based on the following assumptions: Interest rate 6%, service life of insulation 30 years, annuity factor insulation 0.0726, service life of technical equipment 20 years and annuity factor technical equipment 0.0872.

The mitigation costs expressed as annualised EURO per ton of avoided CO_2 was used as the economical criterion. The value of 20 €/tCO_{2e} represented an indicative limit of acceptable mitigation costs. Mitigation costs were calculated on the basis of the total annual cost savings (which is annual investment costs minus saved energy costs) per saved CO_2. Negative mitigation costs indicate that the measure is cost effective.

The assessment was also based on the fact that Poland's, new Central Eastern European (CEE) and Baltic member states' building stock is in urgent need for refurbishment. Due to considerable under investment in maintenance of the housing stock in the EU 10, the need for investment will be very high.

The assessment was also based on the assumption that the new retrofit facades will have the following U-values: 0.26 in Baltic countries, 0.25 in Poland and 0.35 (W/m^2K) in Central Eastern European countries while the corresponding values before retrofit are 0.90, 1.20 and 1.50. External insulation method was assessed as being the most common method for the insulation of external walls. Investment costs were calculated for two cases: independent additional insulation of external walls and additional insulation coupled with other needed renovation measures. In the case of independent insulation the assessed investment cost was 44 €/m^2 for Baltic countries, 46 €/m^2 for Poland and 42 €/m^2 for CEE countries. The corresponding cost in the case of coupled retrofit was 26, 28 and 24.

A uniform average energy prices and CO_2 emission factors were used: Average assumed CO_2 emission factor was 0.130 for Baltic countries, 0.293 for Poland and 0.220 for Central Eastern European countries; average assumed energy cost was 0.042 e/kWh for Baltic countries and Poland and 0.045 for CEE countries.

The economical assessment of the refurbishment of eternal walls shows the following results:

Table 27. Economical assessment of the refurbishment of eternal walls (Petersdorff et al. 2005).

External insulation of facade		Baltic countries	Poland	CEE countries
end-energy saving	kWh/m^2a	76	100	107
CO_2 emission savings	**kg/m^2a**	**10**	**30**	**24**
mitigation costs (independent)	€/tCO_2	-3	-28	-75
mitigation costs (coupled)	€/tCO_2	-131	-71	-129
cost-saved energy (independent)	cent/kWh	0.0	-0.8	-1.7
cost-saved energy (coupled)	cent/kWh	-1.8	-2.1	-2.9
amorisation (independent)	a	14	11	9
amorisation (coupled)	a	8	7	5

The result addresses the cost-effectiveness of refurbishment in the context of coupled retrofit. The report also analyses the effect of the chosen U-value after retrofit. These results show that the external insulation is cost-effective also with lower U-values, and the report recommends the increasing of the ambition level of the legislation.

A similar analysis was done for windows. The assumed U-values for Baltic countries, Poland CEE countries were 3.0, 3.5 and 4.0 before retrofit and 1.66, 2.00 and 1.70 after retrofit. The assessed end-energy savings are 159, 156 and

213 kWh/m^{2}a for Baltic countries, Poland and CEE countries. The corresponding CO_2 emissions are 21, 47 and 48 kg/m^{2}a. However, the result shows that an independent measure is not usually cost-effective, but it is economically beneficial to install energy efficient windows where this is part of a necessary replacement within the renovation cycle.

5.3 Summary of the study "Mitigation of CO2 emissions from theEU-15 building stock"

Petersdorff et al. (2004, 2006) have carried out an earlier and corresponding study for the EU-15 building stock. The study analyses the potential of the European building stock in the mitigation of CO_2 emissions considering the EU-15 building stock distinguished by climatic regions, building types and sizes, building age, insulation level, energy supply, energy carrier and emission factors. For the modelling of the European residential building stock the following three types of buildings were looked at: 1) two-storey terrace-end house (living area 120 m^2), 2) small apartment house (less than 1000 m^2) , and 3) large apartment house (larger than 1000 m^2). Three different climatic zones were considered. Finland and Sweden belong to the Northern cool zone; Austria, Belgium, Denmark, France, Germany, Great Britain, Ireland, Luxembourg and the Netherlands belong to the moderate central climatic zone, and Greece, Italy, Spain and Portugal belong to the warm zone. The building stock was also divided to three age groups (before 1975, 1975–1990 and after 1990).

The report uses the following facade U-values for different climatic zones and building ages:

Table 28. U-values for different climatic zones and building ages (Petersdorff et al. 2006).

	before 1975 no retrofit	before 1975 retrofitted	1975–1990	1991–2002	new buildings 2003–2006	retrofit 2003 until 2006	new building after 2006	retrofit after 2006
Cold zone	0.50	0.30	0.30	0.20	0.18	0.18	0.17	0.17
Moderate zone	1.50	1.00	1.00	0.50	0.41	0.41	0.38	0.38
Warm zone	2.60	1.40	1.20	0.60	0.60	0.60	0.48	0.48

Correspondingly assumptions were also made with regard to the U-values of roofs, floors and windows.

The report assesses the CO_2 mitigation during 2002–2020. An assumption was made that the volumes of new construction, demolition and retrofit are 1%, 0.5%

and 1.8% in corresponding order each year. The report shows calculation results for 6 different scenarios, which are as follows:

- Scenario 1 assumes retrofit action without energy related measures (new buildings erected according to regulations and replace elder buildings)
- Scenario 2 assumes that 20% of retrofit measures are combined with energy-efficiency actions
- Scenario 3 (EPBD excluding certificates) Buildings which are subject to the EPBD are assumed to be retrofitted considering energy-efficiency improvements
- Scenario 4 assumes that in addition to Scenario 3 certificates lead to an increased rate of energy retrofit to 40%
- Scenario 5 (Extended EPBD > 200 m^2) assumes an extension of EPBD to all non-residential buildings and multi-dwelling buildings > 200 m^2
- Scenario 6 (Extended EPBD all house types) assumes that small houses are also considered.

The European Directive 2002/91/EC on Energy Performance of Buildings came into force in 2002 and required implementation of the legislation by January 2006. In addition to the aim of improving the overall energy efficiency of new buildings, large existing buildings become a target as soon as they undergo significant renovation. Existing buildings are subject to the Directive if the total useful floor size exceeds 1000 m^2 and an investment in renovation exceeds 25% of the building (without land) value or 25% of the building envelope are subject to renovation.

The report first shows the technical potential, if all retrofit measures (concerning not only facades but roofs, floors and windows as well) covered by the Directive were realised for all the European (EU 15) building stock of 2002 at the same time:

- The overall emission savings associated with the heating the European building stock would amount to 82 Mt/a (EPBD)
- This potential could be increased by 69 Mt/a if the Directive were extended to retrofitting all multi-family houses and all non-residential buildings (Extended EPBD > 200 m^2)
- By extending the Directive to the whole of the European building stock by adding single-family houses the additional potential, compared to the Directive, rises to 316 Mt/a (Extended EPBD all houses).

The report uses the expression "technical potential". It should be rather titled as theoretical potential because building physical, architectural and social-economical reasons form obstacles for this assumption in addition to time-related issues.

Pedersdorff et al. (2006) take into account the fact that the existing building stock cannot be retrofitted at once and that the building stock is not only affected by retrofitting but also by demolition and new construction. The report presents results for the temporal development of the CO_2 emission savings of the European

(EU-15) building stock in the year 2010 under different scenarios. According to the calculation results:

- Compared to a business as usual scenario under which the common practice for energy efficiency is applied to new buildings and retrofit measures, the current EPB Directive leads to CO_2 emission reductions of 34 Mt/a.
- An extension of the scope of the Directive to all non-residential buildings and to all multi-family residential houses, creates an additional emission savings potential, compared to the Directive of 8 Mt/a (Extended EPBD > 200 m^2).
- Assuming a further extension to all buildings in the building stock, the additional potential rises to 36 Mt/a (Extended EPBD all houses).

The large increase of achievable reductions from the second (Extended EPBD > 200 m^2) to the last scenario (Extended EPBD all houses) is due to the following characteristics of small dwellings:

- Single-dwelling buildings dominate the building stock with respect to living space;
- The unfavourable ratio of the building envelope compared to the floor area leads to a high specific heating energy demand.

Especially in Southern European countries, cooling demand becomes increasingly important for the overall energy consumption of a building due to higher requirements regarding thermal comfort. The study found that in warm climatic zones the cooling demand can be reduced drastically by a combination of lowering the internal heat loads and by improved insulation. With the reduction of the heat loads to a moderate level, the cooling demand of a terraced house located in Madrid can be reduced by an additional 85% if the insulation level is improved appropriately.

Two different scenarios were investigated in order to assess the effects of insulation on cooling demand in warm climatic zone:

- In scenario 1 ‘high loads’ an inefficient internal shading device is assumed leading to high solar radiation gain. Old household appliances with high energy consumptions lead to high internal loads. Furthermore, a ventilation strategy with constant air changes is assumed.
- In scenario 2 ‘low loads’ an efficient shading device e.g. external shading, energy efficient household and office appliances and a ventilation strategy, which depends on the outdoor temperature are combined.

The following U-values were assumed for the example building in Madrid: for roof 0.3 W/m^2K (high standard), 1.0 W/m^2K (medium standard) or 3.4 W/m^2K (low standard), for facade .0.5 W/m^2K (high standard), 1.4 W/m^2K (medium standard) or 2.6 W/m^2K (low standard), for window 2.0 W/m^2K (high standard), 3.5 W/m^2K

(medium standard) or 4.2 W/m^2K (low standard) and for ground floor 0.4 W/m^2K (high standard), 1.0 W/m^2K (medium standard) or 1.7 W/m^2K (low standard). According to the assessment not only the insulation of roof but also the insulation of facade matters. For example in scenario 2 (low loads) the cooling energy demand was 10 kWh/m^2a, CO_2 savings 1.95 kg/m^2a and hours of discomfort (> 26 Celsius degrees) 926 hours in the connection of high insulation standard for roof and low standard for other parts while the corresponding figures were 3.0 kWh/m^2a, 0.58 kg/m2a and 599 hours in the connection of high insulation standard both for roof and outer walls.

5.4 Summary of the study "Building Renovation and Modernisation in Europe"

Itard et al. (2008) characterise the external walls in the existing residential building stock. Heat losses through building components are proportional to their heat transfer coefficient and to their surface area. Insulating the largest surfaces with the highest heat transfer coefficient is therefore the most efficient in terms of energy and, for the most part, in terms of economics. Detached houses have a large area of external walls, which makes the insulation of these walls very important. Terraced houses have fewer external walls, which increases the importance of insulating roofs. Multifamily dwellings share a common roof, which reduces its importance and makes the insulation of external walls an issue again. Floor insulation will be more important in low rise buildings than in high-rise buildings. For dwellings with a large glazing percentage, using high efficiency glass is preferable.

There are two main types of external walls; solid walls and cavity walls. Cavity walls consist of two layers (of bricks or concrete for instance) with an air gap or cavity between them. In solid walls, there is no air cavity. When considering the insulation of existing external walls, the most important thing is to determine whether it is a cavity wall or a solid wall. The insulation of cavity walls is a relatively easy task; the cavity wall has to be injected with insulating material, mostly foam. Companies have specialised in this task and a lot of practical experience has been gained. Solid walls, in contrast, are much more difficult to insulate because this can only be achieved by adding insulation material to the outside or the inside of the wall. In general, it is better to insulate walls from the outside, because it avoids the typical moisture problems that often occur with indoor insulation. However, outside insulation is expensive and often not desirable because it changes the whole appearance of the facade. Furthermore, outside insulation may be impossible if the municipal land use plan does not allow for the offset of the facade alignment. Outside insulation is regularly carried out on office buildings and apartment blocks but will remain very difficult for traditional dwellings because the external appearance of the facade is often very important.

The other solution is to insulate the wall indoors. It is cheaper than external insulation, but it causes a non-negligible loss of inside space (5 to 10 cm for each wall) and moisture and condensation problems often occur, not least because the placement of the insulation has not taken into account the interaction between the existing walls, the vapour sealing layer and the insulation material itself. The sustainable design of details, cold bridges for instance, is a key issue. In this sense it would be important to assemble enough data on the typology of solid walls to determine which kind of technical solution may be applied and to estimate the possible energy savings at the level of the building stock. Even now, a rough estimate of the number of brick, stone and concrete solid walls would be helpful. Concrete walls for instance may offer more possibilities for outdoor insulation because various panels may be used to finish the facade.

There are large disparities between the types of walls in the different countries. Finland and France have a very high percentage of solid walls (90% to 100%), the Netherlands a very low percentage (4%) and the United Kingdom about 30%. Cavity walls are more often insulated than solid walls, but in Finland, which has a younger building stock, almost all solid walls have been insulated.

The penetration of double-glazing is high in all countries, and the penetration of triple glazing is low except for Finland and Sweden.

The report gives the following information about the external walls for Austria, Finland, France, the Netherlands and the UK.

Austria
Solid walls are likely to make up the largest part of external walls in the pre-1980 residential building stock. Of these solid walls, mostly of brick, about 80% have no insulation. However, very thick walls (> 0.45 m) are assumed to offer sufficient thermal insulation. Thick brick walls were built mainly before 1919 and this stock is very homogenous. From 1919 to 1944 the dwelling stock became more heterogeneous and several materials were used for walls, like pumice stone. Walls were thinner without any sound or thermal insulation. After 1945 the construction of large housing estates became dominant and from the mid-fifties standardisation started. Thin walls were built with poor sound and thermal insulation. Construction with prefabricated reinforced concrete components was dominant. From 1961 to 1980, walls were built with brick or concrete panel construction. After 1980, there was a renaissance of brick and poured concrete constructions, but these had thermal insulation applied. Solid wall buildings built after 1970 are all insulated, with an insulation thickness increasing from 6 cm to more than 10 cm nowadays. About 1% of the older solid walls are estimated to be insulated (inside insulation) each year. Cavity walls have been used since the eighties in single-family dwellings and are all insulated. In multi-family houses, these walls are very uncommon. The glass percentage in Austrian dwellings varies from 15% to 30%. The highest percentages are found in the more recent building stock. Single glazing is almost non-existent. 90% of the glazing is double glass and 5% is triple glass, mainly in modern low energy or passive houses. Window frames are made from wood, PVC or aluminium with a new trend in wood-aluminium combinations.
Finland

Cavity walls are extremely rare in Finland. Most external walls are solid walls. Due to the cold climate, almost all solid walls (90%) in single-family houses and in the old building stock are insulated. In multi-family houses this percentage is 98%. Non-insulated solid walls are mainly found in pre-1919 dwellings and in log and summer houses. The glass percentage in dwellings varies from small for the building stock before 1945 to average or large after. Dwellings built before 1970 all have double-glazing that is increasingly being replaced by triple glazing. Dwellings built after 1970 all have triple glazing. Considering the whole dwelling stock, about 75% of glazing is triple glazing and about 25% is double-glazing, most of which is found in dwellings built between 1960 and 1980. If single glazing remains, it will be in the pre-1960 building stock. Window frames are made from wood, steel or more recently aluminium.
France
In single-family dwellings the external walls are built of concrete blocks in 83% of cases, of brick cavity walls in 16% and of wood in 2%. Insulation used is 98% polystyrene, 10% mineral wool and 3% others (polyurethane). In the multi-family dwelling stock, the external walls are made of reinforced concrete in 68% of cases, of concrete blocks in 24%, 3% are curtain walls, 2% are cavity brick walls, 2% are solid brick walls and 1% are made of prefabricated concrete panels. Insulation used is 95% polystyrene and 4% mineral wool.
The Netherlands
Of all external walls in the Netherlands 43% have not been insulated. When looking at buildings built before 1971, the figure is 77% (in 2000). Data from 1998 indicate that 59% of cavity walls have been insulated in multi-family buildings. Solid walls are very uncommon (3.5%) and are found practically only in two-family terraced houses built before 1966. Before 1925, walls were mainly of brick. Since then, brick walls are constructed as cavity walls, originally to improve moisture protection. On-site concrete building techniques were introduced only after 1966. From 1970, dwellings are characterised by thicker facades and concrete-brick construction walls. The insulation rate of external walls has been 1.6% per year on average since 1995. The glass percentage of Dutch dwellings remains approximately constant over the years at around 25–30%. There are still 20% of single-family dwellings and 15% of multi-family dwellings with single glazing. The remaining 80% and 85% respectively have double-glazing. Double-glazing was utilised in new dwellings from 1980. Wood and sometimes steel are used for the window frames in buildings built before 1976. Since 1976, PVC, aluminium or wood have been used. The rate at which single glazing is replacing double-glazing has been 2.2% per year on average since 1995.
The UK
40% of external walls are insulated. Almost all insulated walls are cavity walls. Solid external walls are found in 31% of all dwellings and are not insulated. For the whole of the UK, the ACE report gives a figure of 36% not insulated. The pre-1919 dwelling stock consists of 85% solid external walls. For buildings built between 1919 and 1944, this share decreases to 41%, and to 14% for the

building period 1945–1964. In post-1965 dwellings, solid walls are used in less than 10% of the dwellings. 68% of solid walls are estimated to be 9 inch thin brick constructions. The other 32% are divided into timber and half timber frame houses typically built before 1944, “no-fines” houses (concrete panel houses where the concrete is cast in situ) and post-war prefabricated systems. On average, 30% of owner-occupied, 25% of social rented and 50% of private rented houses could be solid wall dwellings. Two thirds of solid wall dwellings are owner-occupied, 18% are in the social rented sector and 16% in the private rented sector. A little less than half of solid wall dwellings are terraced houses, about 25% are semi-detached, about 10% are detached houses and another 10% are multi-family dwellings. Cavity walls are more common and are found in 69% of the dwelling stock, mostly from the post-war period. Only 40% of these cavity walls are insulated.

71% of dwellings are fitted with double-glazing, and the remaining 29% have single glazing for the large part. According to the report Energy Consumption in the UK from the DTI, in 39% of houses more than 80% of the windows are double-glazed.

Renovation activities may vary from demolishing entire buildings to simple maintenance activities. In most cases, energy ambitions are an important reason to renovate (especially for housing associations and municipalities) in combination with the need to replace building components at the end of their service life or to solve comfort problems in the dwellings. However, on the basis of the report, the additional insulation of external walls is not among the typical renovation activities.

Austria and the Netherlands have the highest percentage of the building stock being demolished (0.4 and 0.3% respectively), followed by Finland (0.1%). France, Germany and the United Kingdom have percentages of 0.08%, 0.06% and 0.07% respectively, whereas the percentage of buildings being demolished is lowest in Sweden (0.03%). Demolition of buildings seems to occur mainly in areas of urban renewal in Austria, Germany, France and the Netherlands. In the first three countries, the buildings in these areas also have the common characteristic of being mainly of prefabricated concrete panels.

5.5 Summary of the study "Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries"

Eichhammer et al. (2009) use the following outline for the main construction periods

- old buildings, built before 1975
- intermediate buildings, built between 1976 and 2000 and
- new buildings, built between 2001 and 2030.

Table 7.1 of the report (on page 101) summarises the residential building stock 2004 by construction period. It is interesting that there are quite big differences between the European countries with regard to the division of buildings (in terms of the number of flats) between the periods before 1975 and after 1975. For example in Czech Republic and in Slovakia roughly two thirds of flats are from the period after 1975 while in the most countries the situation is quite the opposite.

Due to regional differences in each country it can be observed that some countries have almost the same amount of single and multi-family buildings, e.g. Portugal, Spain, Austria, Romania, Slovakia, Bulgaria, and Germany. In the Netherlands, Belgium, Luxemburg, Ireland, Norway and United Kingdom the amount of single family buildings is much higher, while the number of multi-family buildings in almost every new EU Member State is twice as high or more than that of single-family buildings. This is very pronounced in the Baltic countries and in Poland (Table 7.1 in Eichhammer et al. 2009).

According to the report, the expected average living area per dwelling increases in all parts of Europe between 2004 and 2030. The total increase of the floor space will be 29% between 2004 and 2030, and an increase of average living area from 88 m^2 up to 97 m^2 per dwelling in 2030 is projected.

The report uses the following values for the characterisation of typical buildings:

Table 29. Characterisation of typical buildings (m^2) (Eichhammer et al. 2009).

		Standard component surfaces (m^2)				
Building type	Dwelling space	Ceiling height	Roof	Facade	Floor	Windows
Single/two family house	120	2.5	90	166	63	29
Large apartment house	1457	2.5	354	1189	354	380

The study uses three climatic zones:

- Cold, above 4,200 heating degree days
- Moderate, between 2,200 and 4,200 heating degree days and
- Warm, below 2,200 heating degree days.

The report also gives the country specific heating degree days (Table 7.3 p. 104). The U-values used are as follows:

Table 30. Energetic standard of building components by climate zone and construction period of the building (Eichhammer et al. 2009).

U-values in Wm²K			
	Old		**Intermediate (LM)**
	Built before 1975 not refurbished	Built before 1975 already refurbished	Build 1976 - 200
Cold Climate Zone			
Roof	0.50	0.20	0.18
Facade	**0.50**	**0.30**	**0.25**
Floor	0.50	0.20	0.19
Windows	3.00	1.60	1.60
Moderate Climate Zone			
Roof	1.50	0.50	0.45
Facade	**1.50**	**1.00**	**0.75**
Floor	120	0.80	0.65
Windows	3.50	2.00	2.75
Warm Climate Zone			
Roof	2.46	1.00	0.65
Facade	**1.97**	**1.40**	**0.90**
Floor	2.50	1.00	0.68
Windows	4.70	3.50	3.85

Source: WI calculations based on EURIMA, Ecofys (2005b); WI (200); IWU (1994); ISIS

The division of countries to the different climatic zones is as follows:

- North-Western Europe (NW Europe):
  - *Cold Climate Zone*: Finland, Iceland, Norway and Sweden;
  - *Moderate Climate Zone*: Austria, Belgium, Denmark, France, Germany,
  - Ireland, Liechtenstein, Luxemburg, the Netherlands and United Kingdom;
- Southern Europe (S Europe):
  - *Warm Climate Zone: Greece, Spain, Italy and Portugal*
- New Member States 2005 (NMS 2005):
  - *Cold Climate Zone: Estonia and Latvia;*
  - *Moderate Climate Zone: Czech Republic, Hungary, Lithuania, Poland,*
  - *Slovakia and Slovenia;*
  - *Warm Climate Zone: Cyprus and Malta;*
- New Member States 2007 and Croatia (New Member States 2007 + CR):
  - *Moderate Climate Zone: Bulgaria, Croatia and Romania.*

Eichhammer et al. (2009) study the overall energy saving potentials by using three different scenarios: Technical potential (Best available technologies and practices), Economic Potential – High Policy Intensity (HPI) (Cost-effectiveness for the whole country), and Economic Potential. Low Policy Intensity (LPI) (Cost-effectiveness for the consumer with usual market conditions). The technological/economic restrictions on the energy savings potentials can be distinguished as follows:

- No restrictions, maximum technical potentials: what can be achieved with the best available technologies available whatever the costs and prices.
- Cost-effectiveness for the whole country: what can be achieved with the best available technologies available, which are economic on a country-wide basis (typically a discount rate of 4% could be used for energy saving investments for this case). Also barriers would be largely removed in such a context.
- Cost-effectiveness for the consumer with usual market conditions: what can be achieved with the best available technologies, which are economic for the consumer with the usual market conditions today and reflecting consumer preferences and barriers (typically a discount rate of 8–15 % or higher could be used for energy saving investments for this case).

In 2030, the achievable reduction of the total unitary consumption of the residential sector including electricity is:

- 41% in the LPI Scenario
- 57% in the HPI Scenario and
- 73% in the Technical Scenario.

For 27 EU countries, in the LPI Scenario the savings arrive to 43 Mtoe (by 2030), In the HPI Scenario the savings are of 104.8 Mtoe and in the Technical Scenario of 163.4 Mtoe.

5.6 Summary of the study "Environmental Improvement Potentials of Residential Buildings (IMPRO-Building)"

The European research project IMPRO (Environmental Improvement Potentials of Residential Buildings) has done an overview of the environmental life cycle impacts of residential buildings in the EU-25. It conducted an analysis of the reduction of environmental impacts that could be gained with help of technical improvement options with a special focus on the main source of environmental impacts of buildings, namely energy use for space heating. The report Environmental Improvement Potentials of Residential Buildings (IMPRO-Building) (Nemry et al. 2008) assesses the environmental benefits and the costs associated with these improvement options.

IMPRO project derived a typology of the residential buildings in the 25 EU countries (EU-25). The country specific statistical data was divided in three groups: single-family houses (including two-family houses and terraced houses), multi-family houses and high-rise buildings as follows:

1) Single-family houses (SI) include individual houses that are inhabited by one or two families. Also terraced houses are assigned to this group
2) Multi-family houses (MF) contain more than two dwellings in the house
3) High-rise buildings[27] (HR) were defined as buildings that are higher than 8 storeys[28].

Over half of the residential buildings in Europe are single family houses (53%), while the share of multi-family buildings is 37% and the share of high-rise buildings is 10% (calculated by the number of dwellings) Nemry et al (2008) evaluated the improvement potentials on a European level. The project studied where there are the greatest improvement potentials and how the measures should be directed in order to achieve rapid reductions on the level of whole Europe. The project also carried out cost analyses and explained to which types and zones these reductions should be directed in order to ensure minimal cost effects or maximal cost savings in the long run. From this point of view sufficient results can be gained analysing only 22 out of 53 building types (of existing buildings).

Nemry et al (2008) derived from EUROSTAT and other references that

- the volume of the European residential building stock is 14.8 milliard m^2 (calculated in floor area) of which 7.38 milliard are single family houses and 7.46 milliard m^2 multifamily and high rise buildings.
- Derived from (Nemry et al 2008) their building models (Table 9) the corresponding façade areas are 12.6 milliard m^2 for single family houses and 4.45 milliard m^2 for multifamily and high rise buildings, total area 17.1 milliard m^2 (round 80% of the building stock).
- Assessed energy consumption of the building stock was 71 701 MJ/m^2*a (single family houses 41 348 and multifamily and high rise buildings 30 353 MJ/m^2*a).
- Environmental impact saving potential in terms of CO_2 savings was assessed to be 360 Mt/year in total. This saving was reached through different combinations of roof insulation, external wall insulation and renewing sealings. The share of external walls from the assessed total saving was 110 Mt CO_2/year. IMPRO assesses that this can be reached when all external walls are refurbished to the level of 0.12 W/m^2K.

27 the definition of "high-rise building" differs from one country to another. In Estonia, for instance, a high-rise building has at least 14 storeys whereas, in south European countries, high-rise buildings are defined as having more than five storeys.

28 One special building type, the panelised structure buildings, is found in most (especially eastern European) countries. In literature and statistics, they are either accounted for amongst high-rise buildings or multi-family buildings. In the EU-25, altogether 34 million dwellings or 17% of the whole buildings stock are included in panel buildings.

In practice, the environmental impact reductions are not required on EU level but on country level. Each EU member country has to reduce the greenhouse gas emissions and energy consumption on a national level. Thus also analysis on more detailed level should be done on country level. Referring to the list above about the feasibility of the improvements concerning all the technical potential, IMPRO assumed that each building belonging to the 22 (out of 53) assessed building types would be refurbished. In reality this presumably is not the case, but the true potential is reached through refurbishing a certain amount of buildings in all categories and climate zones.

Consideration of saving potentials was restricted to building structures in IMPRO. It is mentioned (Nemry et al. 2008, chapter 1.2) that changes in heating and cooling systems were disregarded. This is a reasonable limitation to the approach. In practice, however, these issues are not totally separable. The results for the improvement with help of new sealing (Nemry et al. 2008, Figure 7.8) have remarkably high impact.

Reduction in ventilation losses should not be counted as reduction in ventilation since – as pointed out also in IMPRO report (Nemry et al 2008) several times – that leads to problems with air quality and moisture. The reduction of uncontrolled air flow through the envelope should be compensated with the ventilation system, whether natural or air conditioning. Thus the saving potential may not be as huge as expressed in IMPRO, unless an efficient heat (/cool) recovery system is added to the building. However, since sealing to a certain extend is a cheap method and uses very little material, it should be used as a part of any improvement measure.

5.7 Summary and discussion

The existing information was used by the SUSREF project as background knowledge when assessing the significance of alternative renovation concepts. The previous studies have mainly focused of the assessment of the technical potential and the SUSREF project tries to provide additional information and complete the results by assessing the effect of other limiting factors and possibilities. The real potential of the refurbishment of the building stock is not only based on the technical potential. There are several reasons for that:

- the refurbishment of external walls causes economic and environmental savings in long run but it may also cause big social impacts and bring people to unequal or poor position when mandatory rules are given
- part of the existing building stock in the countries under scrutiny is in poor condition. The retrofit and especially ambitious levels of retrofit may be totally beyond the possibilities when the refurbishment costs approach the costs of new building
- even if low U-values were beneficial from the straightforward economical view point, those may be impossible because of technical reasons. The optimal insulation thicknesses and placement depends on the building physical behaviour of structures

- although the external additional insulation is a common method for insulation of outer walls, it is not possible in a number of cases. The covering of facades may be unacceptable because of architectural reasons.

In the context of facade refurbishment the issues of townscape and cultural heritage become essential questions. Refurbishing the façade can change the appearance of a building tremendously. That of course depends on the refurbishment method chosen. However, it is difficult to quantify the cultural or visual value of a building or a façade. Thus it makes it difficult to compare the value gained with for example reduced energy consumption with the value of preserving a beautiful, rare, historic or other ways special façade. It should be kept in mind in the assessments and scenarios that we cannot assume or recommend that all houses should be refurbished with help of external insulation or other measures that affect the appearance of the building (outside or inside).

However, the technical improvements and visual appearance are not always in conflict. In many cases buildings can also be made more comfortable looking with help of refurbishment. These issues will be included to the SUSREF approach when assessing the potential and practical solutions for the refurbishment of external walls.

6 Assessment of alternative refurbishment scenarios on environmental and economic impact on European level

6.1 Introduction

This Chapter presents the assessment results of alternative refurbishment scenarios. The objective of the task was to assess the significance of sustainable refurbishment of building envelopes and external walls in Europe.

The assessment was based on the studies and statistics concerning the state and age structure of the European building stock and neighbouring countries and scenarios concerning the alternative possibilities to maintain, refurbish, and renovate the existing building stock with reference to external walls and building facades. The environmental assessment focuses on the impacts on the use of energy and releases of the greenhouse gases (GHGs). In addition, economic assessments have been carried out. The economic assessment focuses on the assessment of life cycle costs and on the impacts on value.

Potential impacts of the refurbishment of external walls include the effects on

- Heating energy and other operational energy use
- Effect on the embodied energy
- GHGs emissions and other harmful emissions and the relative impacts
- Life cycle costs
- Value (financial, aesthetic, cultural)
- Comfort – noise, indoor air quality and illumination
- Disturbance, maintenance, remaining service life
- Safety.

This Chapter studies the environmental and economic potentials in terms of numerical calculations and other assessments. The assessment of potential is based on preliminary and general concepts.

6.2 Discussion about refurbishment criteria and concepts

6.2.1 Introduction

The operational energy and greenhouse gases can be saved with help of a combination of refurbishment measures even though the reduction of heat flux through the building envelope holds the key position. This study concentrates to the renovation concepts of exterior walls but takes also into account other building improvements when the energy saving goal is ambitious.

The main refurbishment concepts for exterior walls and for energy saving measures are as follows

- I: New inner insulation
- E: External insulation
- C: Cavity insulation
- R: Replacing renovation.

The potential of environmental impact saving depends on the building use phase (with help of extra insulation) and the whole process of producing the insulation materials. Material development and production process development also affect the saving potentials.

<u>Windows</u>

The area of openings has a great influence on the heating demand, especially in the region of cold climate. Windows may be – according to their thermal performance – the weakest link in the wall structure. The U-value of windows used in the cold climate is always poorer than that of exterior wall. In the warm and moderate climate this can lead also to extra cooling demand. Energy savings in retrofitting of external walls can be achieved by improving the insulation capacities of a window by using:

- windows with multiple glazing
- low conductivity glasses (argon)
- solar control glazing (sunlight passes in while radiates and reflects heat away)
- coatings with low emissivity
- framing materials with very low conductivity (extruded fibreglass)
- heat recovery from the inner part windows.

6.2.2 Extensive sustainable renovation

Many experiences of European refurbishments show that it is both technically and economically possible to renovate also quite old buildings even so thoroughly that they may be described as passive houses after renovation. The key strategies are

- thorough planning and construction
- very good insulation
- new energy saving windows
- ensuring adequate insulation thicknesses
- mechanical ventilation system with efficient heat recovery
- possibility of inhabitants to stay in their dwellings without intolerable disturbance.

Energy saving potentials of different renovation options in northern Europe are shown in the next table.

Table 31. Estimated heating energy saving potentials in Northern Europe according to VTT assessment.

Energy saving option	**Share of energy consumption in old house %**	**Energy saving potential %**
Improving tightness and insulation of envelope	30	-10...-35
Renewal of windows	26	-15...-30
Improvement of indoor conditions by mechanical ventilation	37	***+5…+25***
Renewal of HVAC technologies		-30...-40

An extensive sustainable renovation is typically a result of a long-term preparation. It is based on the identification of possible damages, technological ageing, poor indoor climate and low energy efficiency. The acceptability of total costs is compared with rent potential, value of facility and possible savings in energy consumptions and carbon footprints. The older the building is the more important reference it is for itself. It is important to identify the aesthetics of the building and make use of similar materials and solutions as was used originally.

The phases and issues of decision making in case of extensive sustainable renovation are shown in the following Table.

Table 32. Phases of sustainable renovation and issues of decision making.

SUSTAINABLE RENOVATION ISSUES				
Solution-oriented investment process	**Principles of implementation solutions**			**Goal-oriented maintenance and use**
	Architecture	**Structural engineering**	**Building services**	
Project preparation and determination of implementation method. Comprehensive planning coordinated by contractor that includes early-stage networking and interactivity Preparation and implementation of sustainable purchases (structural engineering, building services engineering) Interactive and quality assured building Consideration on users' behaviour and development of new kind of rental agreements	Integration with regional objectives (areal planning, energy production and portfolio management) Lay-out, extensibility of the building Adequate life cycle Façade compatible with cultural values Facade with adequate protection that makes use of natural light Main material selections	Better envelope insulation level; thickness control with insulation selections Most energy efficient windows available by competitive bidding Excellent sealing Sun protection Material efficiency Management of building physical behaviour Durable structures that can be cleaned, repaired and recycled Eco-labels and emission classifications	Increased share of renewable energies Needs based (integrated), adaptable and recyclable building services, efficient heat recovery Minimisation of excess capacity and transmission losses Ensuring the possibilities of external air and free cooling Energy efficient lighting Energy efficient pumps and electrical devices Adaptable electrical and technical installation routes Water supply system that prevents unnecessary consumption	Maintenance and user service purchases that meet sustainability criteria Handover inspection Ascertaining building service settings and support for needs oriented use
Adequate life cycle, low risk of damage	Ambient conditions compliant with requirements	Optimal energy efficiency	Low primary energy, small carbon footprint	
reasonable building costs – lower facility costs – higher market values – better utility values				

6.2.3 Criteria for replacing renovation

A number of outdated rental residential houses and some suburbs have been demolished and replaced by new buildings instead of carrying out heavy renovation projects in Europe (Itard et al. 2008). Many residential buildings have originally been planned to be demolished at the renovation age, for example the water pipes have therefore been encased in concrete. Many heavy renovations have caused structural damages with serious moisture problems in which cases the consequences of renovation have proven to be intolerable. Outdated houses usually cannot be renovated to be as sustainable as totally new buildings especially if more and more strict energy codes regulate the projects. The number of occupants and the types of dwellings will stay after renovation quite unchanged although the needs for different dwellings change in the course of time. If buildings in very bad condition locate in highly appreciated area the heavy renovations may not be economically justified compared to replacing renovation.

Based on the information about the current rates of the demolition of building stock, on the expected impact of new energy regulations, and on the age structure and condition of building stock, we can assume that about 10–20% of the European building stock will be demolished during the following 10 years. The demolition of buildings will be directed on the most deteriorated buildings. Thus the demolition rates will be higher in the Eastern Europe and in Baltic countries that in other parts of the EU.

Table 33. Criteria and possibilities for added value in the context of sustainable replacing renovation compared to ordinary renovations in the case of deteriorated and outdated buildings.

	Economic impacts	**Environmental impacts**	**Social impacts**
Replacing renovation	Local appreciation Investment cost Annual capital and maintenance cost Better development of resale values Profit rates	Less needs for earth mass transfers Better manageable local energy production/renewable energy Lower consumptions and carbon footprint Better material efficiency Better waste management Better structural sustainability Longer service life Lower damage risks	May increase the appreciation of whole local area although only some buildings are replaced Better accessibility and access Better functionality and adaptability Better aesthetics Better thermal comfort and air quality Makes it still possible to enjoy of familiar local services May rise also image of whole municipality
Demolition and re-use of old building	Exploitation of infrastructures Development of demolishment technologies Demolition costs May cause losses for share owners of old house	Reusability of demolish ed products	Better Image May cause great disappointment feelings for share owners of old house
Boundaries	Effective financial	Radical decreasing of	Temporary dwelling

	Economic impacts	Environmental impacts	Social impacts
	instruments Steering and motivating support mechanisms Differentiation of real estate tax according to energy classification Cultural values	environmental hazards	Better spatial functionality

6.3 SUSREF assessment approach

6.3.1 Assessed Refurbishment measures

The study focuses on the renovation concepts of exterior walls but also takes into account other building improvements when the energy saving goal is very ambitious. When considering the insulation of existing external walls, it is important to determine whether the insulation can be installed to the cavities or onto the solid wall. In the cases of solid walls the options are either to install the insulation outside or inside of the wall. In this study the assessment is made for the following four main exterior wall refurbishment concepts:

- **I:** Internal improvement of insulation of external wall without other improvements of the facade or the building. Simultaneous minor improvement of other issues (improvement of air tightness and adjustment of HVAC systems)
- **E:** External improvement of insulation of facades. Simultaneous minor improvement of other issues (improvement of air tightness and adjustment of HVAC systems)
- **C:** Input of insulation into cavities of existing walls including connected repair works. Simultaneous improvement of other issues (improvement of insulation, improvement of air tightness, plastering of facades and adjustment of HVAC systems)
- **R**: replacing sustainable renovation of the building covering the renewing or remarkable increasing of insulation of walls and improvement of thermal performance of windows, improvements of insulation of external walls, roofs and base floor that enable insulation to the levels of passive house demands and improvements of tightness and renewing of HVAC (heat recovery, adjustment of ventilation and heating, space specific energy demand).

In the context of environmental calculations the assessment considered the energy saving because of improved insulation of external walls. Economical calculations (energy savings and corresponding economical effects) considered the energy saving on building level.

6.3.2 Assessment levels

These concepts were first studied for selected case countries and case cities, considering one warm (Barcelona), one moderate (Manchester), and one cold (Jyväskylä, Finland) climate condition. After that the scope was widened to the climate zone level (potential effects in warm climate zone, moderate, and cold climate zone), and to the level of whole European building stock.

The project defined certain base cases to represent the existing walls in the selected countries. The base cases for single family houses in cold climate include a wood frame building with mineral wool and gypsum board, where the façade is made either from brick or wood. The base case for multifamily building is a concrete sandwich structure. The basic cases for moderate and warm climate were solid stone and cavity wall buildings for both small house and multi-storey options. Although the real variations with regard to structures and present U-values and the overall quality of walls are high, this was assessed to be a justified approach. Information about typical existing walls, renovation solutions, and costs was collected from VTT (Finland), BRE (the UK) and TECNALIA-Construcción (Spain).

The country level results were aggregated to climate zones and to the whole Europe with help of the volume data described in the following chapter.

6.3.3 Statistics and building typology

SUSREF analysis exploited the building typology and volume data derived in IMPRO project (Nemry et al. 2008). In the SUSREF context the new building types were discarded, since new buildings are not potentially under refurbishment actions yet for a long time. In order to understand and analyse the building stock in EU the existing building types derived from IMPRO were collected into one table based on the external wall types.

Further simplification of the building typology was made. The building types were categorised according to building materials and structure types in order to understand the dominant external wall structures in different locations and time periods and to map what kind of refurbishment concepts would be feasible to different parts of the building stock. Four main categories of external walls were constituted:

1) solid stone walls
2) cavity walls
3) insulated stone walls, and
4) wooden structures.

Inside these main categories the refurbishment concepts for buildings of different age don't differ significantly from each other. Thus, with regard to the economic assessment it is possible to assess the potential without considering the age structure.

Single family houses were separated from multifamily and high rise buildings. The same climate zone division was followed in SUSREF as used in IMPRO.

6.3.4 Assumptions for determining the amounts of refurbishments

The total wall areas of the European residential building stock were summarised based on IMPRO data (Nemry et al. 2008). The corresponding façade areas are 12 600 million m^2 for single family houses and 4 450 million m^2 for multifamily and high rise buildings.

The refurbishment volumes were assessed with help of the following assumptions:

According to Eurostat (Eurostat is the statistical office of the European Union) it is possible to make assumptions presented in Table 34 concerning refurbishment potentials of facades in Europe.

Table 34. Assumed maximal potential of SUSREF concepts on long sights in Europe.

Adding new/more insulation will be relevant for 40–60% of the building stock during 10 years being dependent on building age and climate zone.
Stone walls will not usually be insulated outside, only in case of an extensive sustainable renovation.
Demolition of 5% of the present building stock will take place during next 10 years.
Increase of 7% of present building stock will take place during next 10 years.
The walls already insulated or replaced by new ones have not been included to the amounts of potential refurbishments (SusRef concepts). However some energy saving actions will be done also for those during the next 10 years. When analysing the total significance of wall refurbishment it was assumed that the relative importance of those actions is so small that they have not been separately taken in account.
There is a certain number of buildings where there are either no possibilities or no 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 (SUSREF 4) has been preferred instead of separate actions.

The estimates presented in Table 35 were chosen to represent the potential of SUSREF Concepts during the coming 10 years:

Table 35. Realistic estimation of external walls to be refurbished.

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.

6.4 Environmental assessment

6.4.1 Introduction

The environmental assessments are mainly based on the assessed changes in the energy consumption because of additional heat insulation. The changes were assessed on the basis U-value calculations. The heat losses through the wall structure were calculated according to the local average weather conditions. The cooling energy calculation was excluded from the energy study, because the cooling energy demand is mainly dominated by other factors than U-values, such as solar shading, internal gains etc.

Insulation options (externally, internally or to the cavities) were assessed according to the cold (Finland), moderate (Manchester) and warm (Barcelona) climate and the weather conditions correspondingly based on the data of Jyväskylä, Manchester and Barcelona. This calculation formed the bases for the energy and greenhouse gas savings assessment also for the whole Europe. In the European level assessment the case study values were corrected by using climate coefficients which are based on the specific heating degree days (Table 36).

Table 36. Assumed weather conditions for different cases.

Month	Length of the month	Inside temperature	Average outside temperature, Jyväskylä	Average outside temperature, Manchester	Average outside temperature, Barcelona
	hours	°C	°C	°C	°C
I	744	21	-10	3	9
II	672	21	-10	4	10
III	744	21	-5	6	12
IV	720	21	1	8	14
V	744	21	9	12	17
VI	720	21	14	14	21
VII	744	21	16	16	24
VIII	744	21	14	16	24
IX	720	21	8	13	22
X	744	21	3	10	18
XI	720	21	-2	6	13
XII	744	21	-7	4	10

The annual heat loss through the wall structure was calculated according to the equation:

$Q_{loss} = U\,(Ti - To)\Delta t/1000$
Q_{loss} is energy transmission through the structure, kWh
U is the coefficient of heat transfer, W/m^2K
Ti is internal temperature, °C
To is the average temperature, °C
Δt is the length of the period.

The required U value in the case of SUSREF concept 4 was calculated with help of IDA. The refurbishment concepts (SUSREF1-4, chapter 6.3.1) are presented in the following Tables.

Table 37. Refurbishment concepts for cold **climate** (Finland, Jyväskylä).

House type and description	SUSREF Base case	SUSREF Concept 1	SUSREF Concept 2	SUSREF Concept 3	SUSREF Concept 4
		Internal insulation	External insulation	Cavity insulation	Extensive sustainable renovation
Small single family house Wooden load bearing frame, mineral wool insulation, gypsum board, façades from brick or wood	u-value 0.36	50 mm, SPU, λ = 0.024, u-value 0.20	120 mm mineral wool, λ = 0.041 u-value 0.17	-	SPU XT, λ = 0.015 30+54+30 mm U-value wall 0.09 $W/m^2/K$, window 0.70 $W/m^2/K$, n50 = 0.6 1/h
Multifamily, multi-storey house Concrete sandwich element	u-value 0.36	50 mm, SPU, λ = 0.024, u-value 0.20	120 mm mineral wool, λ = 0.041 u-value 0.17	-	SPU XT, λ = 0.015 30+54+30 mm u-value wall 0.09 $W/m^2/K$, window 0,70 $W/m^2/K$, n50 = 0.6 1/h

Table 38. Refurbishment concepts for moderate climate (UK, Manchester).

House type and description	SUSREF Base case	SUSREF Concept 1	SUSREF Concept 2	SUSREF Concept 3	SUSREF Concept 4
		Internal insulation	External insulation	Cavity insulation	Extensive sustainable renovation
Small single family house Solid stone or cavity wall, façades from stone or brick	u-value 1.0	50 mm, mineral wool, λ = 0.045 Creating new dry lining wall u-value 0.5	70 mm phenolic foam λ = 0.020 External rain screed render applied on top u-value 0.39	160 mm mineral wool, λ = 0.05 u-value 0.26	30+20+40 mm SPU-XT λ = 0.019, u-value wall 0.15 $W/m^2/K$, roof 0.7 $W/m^2/K$, base floor 0.25 $W/m^2/K$. Heat recovery rate 80%, n 50 = 0.6 1/h
Multifamily, multi-storey house Stone	u-value 0.86	75 mm, mineral wool, λ = 0.045 Creating new dry lining wall u-value 0.38	90 mm polyurethane, λ = 0.024 u-value 0.20	160 mm mineral wool, λ = 0.05 u-value 0.24	30+20+40 mm SPU-XT λ = 0.019, u-value wall 0.15 $W/m^2/K$, roof 0.7 $W/m^2/K$, base floor 0.25 $W/m^2/K$. Heat recovery rate 80%, n50 = 0.6 1/h

Table 39. Refurbishment concepts for warm climate (Spain, Barcelona).

House type and description	SUSREF Base case	SUSREF Concept 1	SUSREF Concept 2	SUSREF Concept 3	SUSREF Concept 4
		Internal insulation	External insulation	Cavity insulation	Extensive sustainable renovation
Small single family house Solid stone or cavity wall, façades from stone or brick	u-value 1.0	50 mm, mineral wool, λ = 0.045 u-value 0.55	80 mm polystyrene, λ = 0.033 u-value 0.3	160 mm mineral wool λ = 0.05 u-value 0.26	30+20+40 mm SPU-XT λ = 0.019, u-value wall 0.15 $W/m^2/K$, roof 0.7 $W/m^2/K$, base floor 0.25 $W/m^2/K$. Heat recovery rate 80%, n50 = 0.6 1/h
Multifamily, multi-storey house Stone	u-value 0.50	40 mm, mineral wool, λ = 0.045 u-value 0.34	80 mm polystyrene, λ = 0.033 u-value 0.3	160 mm mineral wool λ = 0.05 u-value 0.26	30+20+40 mm SPU-XT λ = 0.019, u-value wall 0.15 $W/m^2/K$, roof 0.7 $W/m^2/K$, base floor 0.25 $W/m^2/K$. Heat recovery rate 80%, n50 = 0.6 1/h

6.4.2 Energy sources and emissions

The decision about the chosen energy source significantly affects the final results. This report makes use of the same energy mixes as used by the IMPRO project (Table 20). Because the energy production will probably improve during the next ten years in terms of greenhouse gases, the environmental impacts from heating houses will improve correspondingly. This effect, however, is not taken into account in this assessment.

Emissions for different energy source are based on the literature data. The emission factors for pre-combustion of fuels are based on NREL[29] and stationary combustion based on IPCC Guidelines about stationary combustion data for commercial buildings (IPCC 2006). Electricity production data is based on ELCD database for EU 27 mix (2002)[30]. Heat production is calculated according to main source of climate region. The factors used for describing the global warming potential of greenhouse gases are based on IPCC WG 1 report (IPCC 2001). Carbon footprint for fuels is calculated by using the following global warming

29 NREL 2007. Source energy and emission factors for energy use in buildings. M. Deru & P. Torcellini. Technical report NREL/TP-550-38617. Revised June 2007. NREL National Renewable Energy Laboratory.

30 http://lca.jrc.ec.europa.eu/lcainfohub/datasetList.vm?topCategory=Energy+carriers+and+technologies&subCategory=Electricity

potentials: 1 for carbon dioxide (CO_2), 25 for methane (CH_4) and 298 for nitrous oxide (N_2O). Results are shown in the Table 40.

Table 40. Heating energy carrier mix for cold, moderate, and warm climate countries (based on IMPRO-project).

	Solid fuels	Oil	Gas	Electricity	Heat	Renewable energy
Zone 1	0.7%	33%	37%	12%	0.1%	18%
Zone 2	4.7%	17%	51%	5.0%	15%	6.9%
Zone 3	0.6%	7%	1.0%	25%	51%	15%

Table 41. Carbon footprint for the energy consumption.

	Carbon footprint (CF), g CO_2 equivalent /kWh
Solid fuels (assumed coal)	343
Oil	268
Gas	202
Electricity EU 27, for all climate zones	898
Electricity, Spain	1119
Heat mix (Z1 countries)	270
Heat mix (Z2 countries)	245
Heat mix Z3 (countries)	310
District heat (Finland)	225
Renewable energy	0

6.4.3 Assessment results for different cases

The annual energy and greenhouse gas savings compared to the base case are presented for the studied single family house and multi-storey building in the following Tables.

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Table 42. Annual energy and greenhouse gas savings in a **single family building** with help of refurbishment (external wall).

	Concept I Internal insulation	Concept E External insulation	Concept C Cavity insulation	Concept E Extensive Sustainable renovation
Cold climate – Finland, Jyväskylä, single family house				
Reduction in energy consumption kWh/facade-m^2/y	26	31		43
Reduction in energy consumption kWh//floor-m^2/y	30	35	-	50
Reduction in carbon foot print kg CO2/wall-m^2 /y electricity	5	6	-	9
Moderate climate – UK, Manchester, single family house				
Reduction in energy consumption kWh/facade-m^2/y	51	62	75	87
Reduction in energy consumption kWh//floor-m^2/y	59	72	87	100
Reduction in carbon foot print kg CO^2/wall-m^2 per year, gas boiler	10	13	15	18
Warm climate – Spain, Barcelona, single family house				
Reduction in energy consumption kWh/facade-m^2/y	19	29	31	36
Reduction in energy consumption kWh//floor-m^2/y	22	34	36	41
Reduction in carbon foot print kg CO2/wall-m^2,per year, electricity	21	33	35	40

Table 43. Annual energy and greenhouse gas savings in **multi-storey building** with help of refurbishment (external wall).

	SUSREF Concept 1 Internal insulation	SUSREF Concept 2 External insulation	SUSREF Concept 3 Cavity insulation	SUSREF Concept 4 Extensive sustainable renovation
Cold climate – Finland, Jyväskylä, multi-storey building				
Reduction in energy consumption kWh/facade-m^2/y	26	31		43
Reduction in energy consumption kWh//floor-m^2/y	30	35	-	50
Reduction in carbon foot print kg CO^2/wall-m^2, per y, district heat	6	7	-	10
Moderate climate – UK, Manchester, multi-storey building				
Reduction in energy consumption kWh/facade-m^2/y	42	67	63	73
Reduction in energy consumption kWh//floor-m^2/y	48	78	73	85
Reduction in carbon foot print kg CO^2/wall-m^2, per y, gas boiler	8	14	13	15
Warm climate – Spain, Barcelona, multi-storey building				
Reduction in energy consumption kWh/facade-m^2/y	7	11	11	15
Reduction in energy consumption kWh//floor-m^2/y	8	13	13	17
Reducction in carbon foot print kg CO^2/wall-m^2, per y, electricity	8	13	12	16

6.4.4 Results for the European building stock

Table 27 extends the estimated potentials calculated on the basis of the studied cases to the climate zone level. The European building stock magnitude, heating degree days and correction coefficients for the calculations of refurbishment potentials are presented in the following Tables.

Table 44. European building stock and HDD according to the IMPRO project.

	HDD	Building stock, million m^2	correction coefficient for climate zone
Warm climate			
Malta	564	11	0.3
Cyprus	787	40	0.4
Portugal	1 302	337	0.7
Greece	1 698	351	0.9
Spain	**1 856**	**1 454**	**1**
Italy	2 085	2 076	1.1
France	2 494	2 109	1.3
sum		**6 378**	
Moderate climate			
Belgium	2 882	359	0.9
The Netherlands	2 905	561	0.9
Ireland	2 916	125	0.9
Hungary	2 917	221	0.9
Slovenia	3 044	45	0.9
Luxembourg	3 216	21	1.0
Germany	3 244	3 463	1.0
United Kingdom	**3 354**	1 567	**1**
Slovakia	3 440	82	1.0
Denmark	3 479	230	1.0
Czech Republic	3 559	237	1.1
Austria	3 569	292	1.1
Poland	3 605	706	1.1
sum		**7 909**	
Cold climate			
Lithuania	4 071	62	
Latvia	4 243	45	
Estonia	4 420	28	
Sweden	5 423	338	
Finland	5 823	151	1
sum		**624**	
Total		14 911	

Table 45. Refurbishment potentials for the European residential building stock.

	Concept I Internal insulation	Concept E External insulation	Concept C Cavity insulation	Concept R Replacing renovation
Cold climate – single family houses				
Wall area altogether million m^2	315	315	-	315
Walls to be refurbished 2011–2020 million m^2	30	65	-	80
Energy savings million kWh/ renovated area	800	2 000		3 400
Carbon foot print savings million kg CO_2/renovated area and year, Heat Z3	240 million kg CO_2/30 million m^2	620 million kg CO_2/65 million m^2	-	1 040 million kg CO_2/110 million m^2
Moderate climate – single family houses				
Wall area altogether million m^2	3 490	1 070	2 350	3 490
Walls to be refurbished 2011–2020 million m^2	350	200	650	900
Energy savings million kWh/ renovated area	17 900	12 500	49 300	73 100
Carbon foot print savings, million kg CO_2/renovated area and year, Heat Z2	5 400 million kg CO_2/y, 350 million m^2	3 100 million kg CO_2/y, 200 million m^2	12 100 million kg CO_2/y, 650 million m^2	17 900 million kg CO_2/y, 900 million m^2
Warm climate – single family houses				
Wall area altogether million m^2	3 200	1 400	1 800	3 200
Walls to be refurbished 2011–2020 million m^2	300	300	450	800
Energy savings million kWh/ renovated area	6 100	8 800	13 900	28 000
Carbon foot print savings, million kg CO_2/renovated area and year, Heat Z1	1 800 million kg CO_2/y, 320 million m^2	2 600 million kg CO_2/y, 300 million m^2	4 200 million kg CO_2/y, 450 million m^2	8 300 million kg CO_2/y, 800 million m^2
Cold climate – multi-story house				
Wall area altogether million m^2	182	137		182
Walls to be refurbished 2011-2020 million m^2	20	30		45
Energy savings million kWh/renovated area	500	9 200		1 900
Carbon foot print savings, million kg CO_2/renovated area and year, Heat Z3	160 million kg CO_2/y, 20 million m^2	280 million kg CO_2/y, 30 million m^2	0	600 million kg CO_2/y, 45 million m^2
Moderate climate – multi-story house				
Wall area altogether million m^2	1 170	680	500	1 170
Walls to be refurbished 2011–2020 million m^2	100	140	125	300
Energy savings	4 200	9 400	7 900	22 000

	Concept I Internal insulation	Concept E External insulation	Concept C Cavity insulation	Concept R Replacing renovation
million kWh/ renovated area				
Carbon foot print savings, million kg CO_2/renovated area and year, Heat Z2	1 000 million kg CO_2/y, 100 million m^2	2 300 million kg CO_2/y, 140 million m^2	1 900 million kg CO_2/y, 125 million m^2	5 400 million kg CO_2/y, 300 million m^2
Warm climate – multi-story house				
Wall area altogether million m^2	1 620	750	870	1 620
Walls to be refurbished 2011–2020 million m^2	100	150	220	400
Energy savings million kWh/renovated area	600	1 700	2 400	5 900
Carbon foot print savings, million kg CO_2/renovated area and year, Heat Z1	200 million kg CO_2/y, 100 million m^2	500 million kg CO_2/y, 150 million m^2	700 million kg CO_2/y, 220 million m^2	1 800 million kg CO_2/y, 450 million m^2

From Table 45 it can be calculared by summing up the results for different climate zones and through the refurbishment concepts 1–4 that the total CO_{2equ} 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.

6.5 Economical assessment

6.5.1 Basic approach

Economical analyses are based on the calculation of life cycle cost. According to ISO 15686-5 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 throughout the lifecycle. The application of LCC methodology is based on systematic analysis process as shown in Figure 34.

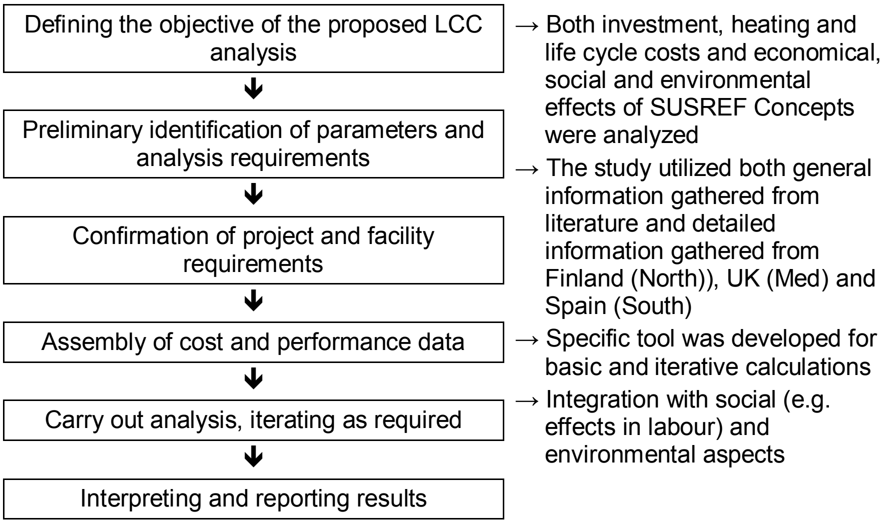


Figure 34. Application of the economical methodology.

The results of economical analyses of energy efficient solutions are usually 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 cost factors of life cycle costs are presented in Table 46. This is calculated by summing up of activated costs in different years for present with present unit costs but also taking the foreseen realized costs into account in case of energy cost.

Because of the predictive nature of life cycle costing methods, sensitivity analyses are often important in the connection of life cycle economics. Sensitivity analysis may be based on classification including for example the three steps: basic – pessimistic – optimistic.

Table 46. Life Cycle Cost factors.

Type of life-cycle cost	Description
Building cost	Costs including all material, labour and sub costs caused by construction
Financial cost	Price of money. **Real rate** (nominal rate – inflation) is based on real need and price of money
Energy cost	Continual cost caused by the operation of the building including – Heating energy – Cooling energy – Electricity
Maintenance cost	Costs because of maintenance and renewing of components
Environmental costs	Possible costs because of purification of soil, demolition and final disposal, recycling etc.

6.5.2 Baseline and starting values

In the context of environmental calculations the assessment considered the energy saving because of improved external walls. In the context of economical calculations the energy savings and corresponding economical effects considered the energy saving on building level. The specific content of SUSREF concepts in different basic cases and values used in the calculations are presented in previous Tables.

The calculations of heating costs were based on the assumptions that district heating is used in case of blocks of flats and electric heating in case of small houses. The heating energy includes energy consumptions caused by heating of spaces. The proportional needs of heating energy in different climate zones are as follows:

- Z3: 100%
- Z2: 70%
- Z1: 30%.

Pressures for the increase of unit energy costs are caused by the development programmes of energy production companies towards the use of renewable energy sources, rise of energy taxation and other directive decisions. Annual rise percent of + 3–6% can be used. It can also be expected that there will be new kind of pricing models for energy processes. However, the effect of the possible new pricing models was not considered in this study. The time point 1/2011 was selected to represent the cost level of the analyses.

New EU member states' share of annual European refurbishment cost is only 4–7% because of the share of their building stock of the European building stock and because of the remarkably lower price level (40%–80% of the average cost level). The following relative cost levels were used in the case studies:

- Zone 3: Refurbishment unit costs in Finland x 0.95
- Zone 2: Refurbishment unit costs in UK x 1.00
- Zone 1: Refurbishment unit costs in Spain x 1.10.

Single family houses have been distinguished from multifamily houses and high rise buildings because of different costs, concepts and performance requirements of facades.

The economical support for energy related refurbishments will cover 0–25% of construction costs in the near future. Also tax reliefs (due to the rates of renovation loans) are possible in many European countries. This study does not consider the effects of economical steering, fiscal measures and changes of financing costs. However, the study is based on the assumption that the volumes of walls to be refurbished will increase because of these mechanisms.

6.5.3 Economical analyses in different zones and in whole Europe

A simple SUSREF tool was developed for the economical analysis of refurbishment concepts (SUSREF 1–4) in different zones and in whole Europe. The tool will be utilized also when analysing the economics of the concepts to be developed in the SUSREF project. The use of the tool was based on following principles

- unit cost and unit consumption information has been collected from corresponding basic tables (tables 29–34)
- the potential of facade refurbishment (in terms of m^2) (see Chapter 6.3.4) are those values shown in basic tables
- total costs can be calculated with help of refurbishment potential estimations and unit cost information
- economics and payback times can be calculated by comparing investment costs and savings in heating costs with each other
- the increase of labour can be calculated based on average labour cost (euros/m2) and share of labour cost (45% of total cost in situ and in prefabrication industry). The investment cost of 1 million euro corresponds to approximately 11 labour years. In case of inner insulation the assessed share of own work (20%) must be taken into account.

The analysis was extended to the period of 20 years. The cost level indexes published by IMPRO (Nemry et al, 2008) were used. The cost effects were calculated in terms of €/facade-m^2 (wall refurbishment) and €/floor-m^2 (HVAC system related costs). The transformation from €/facade-m^2 to €/floor-m^2 was done as follows:

- €/floor-m^2 = 1.0 x façade-m^2 in case of single family houses and
- €/floor-m^2 = 1.5 x façade-m^2 in case of multifamily houses).

The real renewal needs of windows and HVAC was taken into account. It was assessed that 20% of windows and 50% of HVAC systems are renewed during a ten year period because of other reason than energy saving reasons (technical deterioration etc.).

The renovation period of facades is 15–20 years and the renewing period 35–years.

The calculations don't cover effects on usable space, the importance of which in case of Concept I is remarkable (5–10% decrease of room area). So the real importance of internal renovation actions is based on other matters (acoustics, thermal comfort, aesthetic character…).

The calculation forms a framework of analysis being aware of the fact that in individual cases the costs and economics vary a lot.

The changes in energy consumption presented in Table 47 – Table 52 (second last line, right column) differ from the corresponding values used in environmental calculations because in the context of environmental calculations the assessment considered the energy saving because of improved external walls but in the context of economical calculations the energy savings and corresponding economical effects considered the energy saving on building level.

6.5.4 Cold climate, Basic case Finland

Table 47 – Table 48 show the calculation results for the basic case Finland.

Table 47. Cold climate Basic case: **Finland Single family houses** The investment costs and life cycle costs for different concepts.

	Concept I	**Concept E**	**Concept C**	**Concept R**
Climate Zone: Cold climate Case country: Finland House type: single family Façade type: Bricks or wood (U = 0.36 W/m^2K) Heating type: Electric Energy consumption: 200 kWh/housing-m^2/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution (new surface structure, renewed facade type, insulation type, thickness)	50 mm poly urethane	120 mm mineral wool	Fibre glass wool modules	Walls U = 0.09 Windows 0.70 air tightness number: n50.1/h 0.06
Investment costs [€/facade-m2**]**				
Demolishment of facades	-	-	-	40
Replacing facades	-	-	-	250
Improvement of insulation of facades	15	25	-	25
Other improvement of insulation		-	-	15
Basic plastering of facades	-	110	-	-
Plastering of facades	-	150	-	-
Boarding	30	15	-	-
Improvement of tightness	5	5	-	-
Renewing of windows	-	-	-	300
Total [€/facade-m^2**]**	**50**	**295**		**630**
Adjustment of HVAC	10	10	-	**-**
Renewing of HVAC	-			300
Total [€/floor-m^2**]**	**60**	**305**	**-**	**930**
Total (including HVAC) [€/facade-m^2**]**	**60**	**305**		**930**
Share of cost because of energy saving [€/facade-m^2**]**	**30**	**40**	**-**	
Share of cost because of energy saving [€/floor-m^2**]**	**30**	**40**	**-**	**250**
Energy prices [€/kWh**]**	**0.09**	**0.09**		**0,09**
Change in energy consumption [kWh/floor-m^2/y**]**	**-45**	**-50**		**-150**

The investment costs and life cycle costs for different concepts

Labour impacts included (in terms of man years)

Table 48. Cold climate (Z3) Basic case: **Finland Multi-family houses**. The investment costs and life cycle costs for different concepts.

	Concept I	**Concept E**	**Concept C**	**Concept R**
Climate Zone: Cold climate Case country: Finland House type: multifamily Façade type: Concrete sandwich (U = 0.36 W/m²K) Heating type: district heating Energy consumption: 200 kWh/housing-m²/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution	50 mm polyurethane	120 mm mineral wool	Fiber glass wool modules	Walls U = 0.09 Windows 0.70 air tightness number n50.1/h 0.06
Actions [€/facade-m2]				
Demolishment of facades	-	-	-	50
Replacing facades	-	-	-	335
Improvement of insulation of facades	10	25	-	25
Other improvement of insulation		-	-	30
Basic plastering of facades	-	110	-	-
Plastering of facades	-	150	-	-
Boarding	30	15	-	-
Improvement of tightness	5	5	-	-
Renewing of windows				360
Total [€/facade-m2]	**45**	**295**	**-**	**800**
Total [€/facade-m²]	**30**	**195**	**-**	**550**
Adjustment of HVAC	10	10	-	**-**
Renewing of HVAC	-	-	-	300
Total [€/floor-m²]	**40**	**205**	**-**	**850**
Total (including HVAC) [€/facade-m²]	**60**	**310**	**-**	**1200**
Share of cost because of energy saving [€/facade-m²]	**25**	**40**	**-**	**275**
Share of cost because of energy saving [€/floor-m²]	**15**	**30**	**-**	**415**
Energy prices [€/kWh]	**0.06**	**0.06**	**-**	**0.06**
Change in energy consumption [kWh//floor-m²/y]	**-45**	**-50**		**-150**

In the Northern countries the share of owner-occupied flats and houses is very high, which means also a challenge for the management and support of refurbishment projects. The impact of extensive sustainable renovation is the best in terms of sustainable building criteria.

6.5.5 Moderate climate, Basis case UK

Table 49 – Table 50 show the results of the UK case.

Table 49. Moderate climate Basic case: **UK Single family houses.** The investment costs and life cycle costs for different concepts.

	Concept I	**Concept E**	**Concept C**	**Concept R**
Climate Zone: Moderate climate Case country: UK House type: Single family Façade type: Stone (U-value 0.85 W/m^{2}K) Heating type: Gas Energy consumption: 180 kWh/housing-m^2/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution (new surface structure, renewed facade type, insulation type, thickness). U	Internal wall insulation, creating new dry lining wall 50 mm insulation	70 mm external wall insulation phenolic foam. External rain screed render applied on top	Total fill cavity space with mineral wool	Walls U = 0.12 Windows 0.85 air tightness number n50.1/h 0.06
Actions [€/facade-m^2]				
Demolishment of facades	-	-	-	30
Replacing facades	-	-	-	210
Improvement of insulation of facades	25	30	10	35
Other improvement of insulation	10	10	-	5
Plastering of facades	30	15	-	20
Brickwork of facades	-	-	-	-
Boarding	-	10	-	-
Improvement of tightness	-	10	10	-
Renewing of windows	-	-	-	120
Total [€/facade-m^2]	**65**	**65**	**20**	**420**
Total [€/facade-m^2]	**65**	**65**	**20**	**420**
Adjustment of HVAC	10	10	10	-
Renewing of HVAC	-	-	-	250
Total [€/floor-m^2]	**75**	**75**	**30**	**670**
Total (including HVAC) [€/facade-m^2]	**75**	**75**	**30**	**670**
Share of cost because of energy saving [€/facade-m^2]	**45**	**60**	**30**	
Share of cost because of energy saving [€/floor-m^2]	**45**	**60**	**30**	**190**
Energy prices [€/kWh]	**0.07**	**0.07**	**0,07**	**0.07**
Change in energy consumption [kWh/floor-m^2/y]	**-60**	**-70**	**-85**	**-150**

Table 50. Moderate climate Basic case: **UK Multi-family houses.** The investment costs and life cycle costs for different concepts.

	Concept I	Concept E	Concept C	Concept R
Climate Zone: Moderate climate Case country: UK House type: Multifamily house Façade type: Sandstone (U-value 2.1 W/m^{2}K) Heating type: gas Energy consumption: 180 kWh/housing-m^2/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution (new surface structure, renewed facade type, insulation type, thickness)	Internal wall insulation, creating new dry lining wall 75 mm insulation	90 mm external wall insulation pu. External rain screed render applied on top	Total fill cavity space with mineral wool	Walls U = 0.12 Windows 0.85 air tightness number n50.1/h 0.06
Actions [€/facade-m^2]				
Demolishment of facades	-	-	-	30
Replacing facades	-	-	-	260
Improvement of insulation of facades	25	45	10	35
Other improvement of insulation	10	10	-	5
Plastering of facades	30	25	-	20
Brickwork of facades	-	-	-	-
Boarding of facades	-	12	-	-
Improvement of tightness	-	8	10	-
Renewing of windows	-	-	-	**120**
Total [€/facade-m^2]	**65**	**95**	**20**	**470**
Total [€/facade-m^2]	**40**	**65**	**15**	**315**
Adjustment of HVAC	10	10	10	**-**
Renewing of HVAC	-	-	-	275
Total [€/floor-m^2]	**50**	**75**	**25**	**590**
Total (including HVAC) [€/facade-m^2]	**80**	**115**	**35**	**890**
Share of cost because of energy saving [€/facade-m^2]	**25**	**55**	**35**	**-**
Share of cost because of energy saving [€/floor-m^2]	**15**	**40**	**20**	**185**
Energy prices [€/kWh]	**0.07**	**0.07**	**0.07**	**0.07**
Change in energy consumption [kWh//floor-m^2/y]	**-60**	**-75**	**-85**	**-150**

As the room temperatures are relatively low in cold days, it is possible to improve remarkably both thermal conditions and quality of air by means of SUSREF Concepts.

6.5.6 Warm climate, Case Spain

Table 51 – Table 52 show the results for the basic case Spain.

Table 51. Warm climate Basic case: **Spain Single family houses.** The investment costs and life cycle costs for different concepts.

	Concept I	**Concept E**	**Concept C**	**Concept R**
Climate Zone: Warm climate Case country: Spain House type: single family Façade type: Stone (U-value 1,0 W/m2K) Heating type**:** electric mix Energy consumption: 100 kWh/housing-m2/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution (insulation type, thickness)	40 mm Mineral wood.	80 mm XPS: Extruded polystyrene	Fiberglass wool modules	Walls U = 0.25 Windows 1.00 air tightness number n50.1/h 0.06
Actions [€facade-m^2]				
Demolishment of facades	-	-	-	10
Replacing facades	-	-	-	35
Improvement of insulation of facades	5	25	10	5
Other improvement of insulation	-	15	-	5
Plastering of facades	-	-	-	10
Brickwork of facades	-	-	-	20
Boarding of facades	-	10	-	-
Improvement of tightness	5	5	-	-
Renewing of windows	-	-	-	75
Total [€/facade-m2]	**10**	**85**	**10**	**160**
Total [€/facade-m^2**]**	**10**	**85**	**10**	**160**
Adjustment of HVAC	5	5	5	
Renewing of HVAC	-	-	-	140
Total [€/floor-m^2**]**	**15**	**90**	**15**	**300**
Total (including HVAC) [€/facade-m^2**]**	**25**	**90**		
Share of cost because of energy saving [€/facade-m^2**]**	**15**	**50**	**10**	
Share of cost because of energy saving €/floor-m^2**]**	**15**	**50**	**5**	**95**
Energy prices [€/kWh**]**	**0.11**	**0.11**	**0.11**	**0.11**
Change in energy consumption [kWh//floor-m^2/y**]**	**-30**	**-45**	**-45**	**-80**

Table 52. Warm climate Basic case: **Spain Multi family houses.** The investment costs and life cycle costs for different concepts.

	Concept I	**Concept E**	**Concept C**	**Concept R**
Climate Zone: Warm climate Case country: Spain House type: Multifamily Façade type: Stone (U-value 0,50 W/m^{2}K) Heating type: electric mix Energy consumption: 80 kWh/housing-m^2/y	Internal insulation	External (insulation) layers	Inserting (insulation) materials in cavities in existing walls	Replacing renovation
Description of basis energy saving solution (insulation type, thickness)	40 mm Mineral wood	80 mm XPS: Extruded polystyrene	Fiberglass wool modules	Walls U = 0.25 Windows 1.00 air tightness number n50.1/h 0.06
Actions [€/Façade-m^2]				
Demolishment of facades	-	-	-	10
Replacing facades	-	-	-	25
Improvement of insulation of facades	5	25	10	10
Other improvement of insulation	-	55	-	5
Plastering of facades	-	-	-	10
Brickwork of facades	-	-	-	20
Boarding of facades	-	10	-	-
Improvement of tightness	5	5	-	-
Renewing of windows	-	-	-	75
Total [€/facade-m2]	**10**	**85**	**10**	**155**
Total [€/facade-m^2**]**	**5**	**60**	**5**	**110**
Adjustment of HVAC	5	5	5	-
Renewing of HVAC	-	-	-	140
Total [€/floor-m^2**]**	**10**	**65**	**10**	**250**
Total (including HVAC) [€/facade-m^2**]**	**15**	**95**	**15**	**400**
Share of cost because of energy saving [€/facade-m^2**]**	**5**	**85**	**10**	
Share of cost because of energy saving €/floor-m^2**]**	**10**	**65**	**5**	**90**
Energy prices [€/kWh**]**	**0.11**	**0.11**	**0.11**	**0.11**
Change in energy consumption [kWh/floor-m^2/y**]**	**-20**	**-25**	**-25**	**-60**

6.5.7 Summary of the economical analysis in the European level

Because of the predictive and estimating nature of life cycle costing methods, sensitivity analyses are often important in the connection of life cycle economics. Sensitivity analysis may be based on for example three steps: basic – pessimistic – optimistic. Hence we recognize that the single calculated values are not probably the one exact truth about the matter, but we give a range (+/-25%) where the correct value most probably is.

The summary of economical analyses and the sensitivity analyses are presented in Table 54.

- Basic analysis is a summary of the economical calculations. The figures express the total results assuming that ALL FOUR SUSREF concepts will be realised as explained in tables 47–52.
- Pessimistic analysis assumes that the refurbishment volumes will be 25% smaller than in the basic analysis.
- Optimistic analysis assumes that the refurbishment volumes will be 25% higher than in the basic analysis.

Replacing renovation covers all wall-connected construction works with energy-saving effect. In buildings with new ventilation system, the total costs are about 130 e/floor-m^2 caused by energy saving.

On the whole the increase of labour because of energy saving is over 500 000 man years/year compared the actual situation in Europe.

Table 53. Economical assessment results for **EU-27.**

Area	EU-27	New inner insulation	Cavity insulation	External insulation	Replacing renovation of facades and windows	Total
Energy price (average)	e/kWh	0.08	0.08	0.08	0.08	
Refurbished facades	mill. facade-m^2/y	90	145	90		
Replaced facades	mill. façade-m^2/y				250	
Replaced windows	mill. window-m2				40	
Corresponding floor area	mill.floor-m^2/y	110	175	110	300	
Energy savings	million kWh/y	3 100	3 500	4 400	13 500	
Analysis period	y	20	20	20	20	
Rise of energy price:	%/y	2	2	2	2	
ECONOMICAL EFFECTS						
Difference in unit investment cost	e/floor-m^2	25	30	40	60	
Difference in investment cost	mill.e/y	**2 800**	**5 300**	**4 400**	**18 000**	**27 500**
Difference in heating cost	mill.e/20 y	**-6 200**	**-7 000**	**-8 800**	**-27 000**	**-49 000**
Difference in financial cost	mill.e/20 y	**700**	**1 300**	**1 100**	**4 500**	**7 600**
Difference in Life Cycle Cost	mill.e/20 y	**-2 700**	**-400**	**-3 300**	**-4 500**	**-10 900**
Pay Back time	years	**11**	**18**	**11**	**16**	**18**
SOCIAL AND ENVIRONMENTAL EFFECTS						
Increase of labour	Man years/y	36 000	69 000	57 000	234 000	396 000

Table 54. Sensitivity analysis of economical assessment results in EU-27.

EU -27	Unit	Basic analysis	Pessimistic analysis (25% decreased volumes)	Optimistic analysis (25% increased volumes)
The share of the Total investment cost that is allocated to mere energy renovation *	1000 million euro/year	28	21	35
Annual saving in energy cost (because of assumed refurbishment measures) (considering the real rice of energy costs	1000 million euro/year	-2,5	-2	-3
Difference in annual Life Cycle Cost in average (total)	1000 million euro/20 years	-11	-8	-14
Increase of labour	Man years/year	400 000	300 000	500 000

The economical significance of refurbishment was also roughly estimated for other European countries of which Russia is the biggest one. A scale factor of refurbishments was estimated in comparison to EU-27. The scale factor was based on the volume of building stock (30% of the building stock in other European countries) and on the foreseen refurbishment rate. The latter was assumed to be 50% lower than in the EU.

Table 55. Rough analysis of economical and labour effects of SUSREF Concepts outside EU in Europe.

Europe; outer EU	Unit	Basis analysis	Pessimistic analysis (25% decreased volumes)	Optimistic analysis (25% increased volumes)
The share of the Total investment cost that is allocated to mere energy renovation	1000 million euro/year	14	18	30
Annual saving in energy cost (because of assumed refurbishment measures)	1000 million euro/year	-1.2	-8	-13
Difference in Life cycle Cost	1000 million euro/ 20 years	-5.5	-4	-7
increase of labour	Man years/year	200 000	150 000	250 000

When the life cycle costs and related savings are considered the SUSREF Concepts are economical on the basis of the results. The calculations also show that they have positive impacts on the needs of labour. That means also increase in labour skill training and establishment of new services and companies and expansion of present companies in Europe.

In principle it is possible to significantly improve both thermal conditions and the quality of indoor air by means of SUSREF Concepts. Also physical risks may be lower. Effects on economic values of houses and buildings and flats may be significant because of improved performance and because of aesthetical improvement. The importance of concept development is especially high in the level of zone 2 assessed on the basis of different sustainability criteria.

Refurbishment also improves the resale value. The increase of resale value will be a little higher than unit investment costs (euros/m^2) though this naturally decreases in the run of time.

Other impacts of refurbishment and renovation are gathered to Figure 16. Environmental perspective is emphasized but also social effects may be positive.

POSSIBILITY FOR VALUE-ADDING OF RESIDENTIAL NEIGHBOURHOODS: Replacing renovations, utilization of areal renewable energy resources, development of areal services and traffic

LOCATION 0 ARCHITECTURE 1	AESTHETIC QUALITY 1	ENERGY DEMAND - HEATING 2 - COOLING 0
NEED FOR EVASIVES -/-- BUILDABILITY +	THERMAL COMFORT 1 INDOOR CLIMATE 1	MATERIAL EFFICIENCY 1 BUILDING PHYSICAL PERFORMANCE -
WALL THICKNESS - DAMAGE SENSITIVITY + MARKET VALUE ++	FIRE SAFETY -1 ACOUSTICS 2 HEALTHINESS 1	DURABILITY 2 ENVIRONMENTA IMPACT 2

SUPPORTED BY:

Methods for sustainable procurement of Concepts

Networked construction and maintenance services; One stop shops

Steering mechanisms by states and societies (codes, information, energy iNspections, taxes, financial supports, information…)

Figure 35. Total effects of replacing renovations on performance and values (2 = significant improvement, 1 = minor improvement, 0 = no change, -1 = minor aggravation, -2 = significant aggravation)

6.6 Significance of sustainable refurbishment in Europe

This section compares the results with earlier results achieved in different European research projects (compare Chapter 5) and shows realistic recommendations for significance calculations. The difference in the approach with regard to the earlier reports is that this report

- focuses on the assessment of the real possibilities to refurbish considering that there is a number of buildings that cannot be refurbished because of technical, economical, and cultural heritage reasons
- considers different concepts of refurbishment.

The impact assessed by SUSREF is naturally smaller than that of IMPRO (Nemry et al. 2008).

However, this assessment also shows that the development of good refurbishment concepts is extremely important because the potentially achieved impacts vary a lot as shown for example in Table 45 with regard to potential savings in CO_2 emissions.

The comparison of the results between different studies about saving potentials is not straight forward since all the studies have assessed slightly different things, included different aspects (e.g. all buildings in Europe/residential buildings, any structural refurbishment measures or only external walls, including HVAC systems or not including HVAC systems, etc.) The assessed matter in IMPRO study

(Nemry at al, 2008) is very close to SUSREF study although the assessment approach is different. In the following we compare and discuss the results of IMPRO and SUSREF.

Environmental impact saving potential in terms of CO_2 savings was assessed to be 360 Mt/year in total according to the IMPRO results. This saving was achieved through different combinations of roof insulation, external wall insulation and renewing sealings. The share of external walls from the assessed total saving was 110 Mt CO_2/year. IMPRO assesses that this can be reached when all external walls are refurbished to the level of 0.12 W/m^2K.

The estimated savings of SUSREF concepts 1–4 assessed in SUSREF was 74 Mt/y (section 6.4). The approach of SUSREF differs from that of IMPRO. IMPRO estimated the total theoretical saving when all external walls are refurbished. SUSREF project formulated four concepts and assessed the possible realisation of those concepts.

In addition there were following differences. In IMPRO study it was assumed that all walls to be refurbished could be brought to the U value of 0.12 by adding insulation. There are U value changes from 1.6 and even 2.7 to 0.12. SUSREF aimed at making a realistic estimation with using current understanding about applicable solutions of refurbishment. Much lower target (after the refurbishment) U values were used in SUSREF for concepts of added insulation (SUSREF 1–3). From this point of view also Concept 4, extensive sustainable renovation was introduced. We assume that remarkable enhancements of insulation and quality of living space can be reached only by extensive renovations considering all structures of the house, all sealings of the structures and adjusting or renewing also HVAC systems. In addition there is also a significant difference in the original U-values used for Zone 1. However, very big improvements may also be possible with help of remarkable development of refurbishment concepts.

A sustainable renovation and the issues affecting the targets, options, and success of a single renovation as well as the execution volumes and gained effects on community level (economic, environmental and social effects) are a very complex entity. All the approaches taken to assess these in large scale, such as on the level of whole Europe, are more or less simplistic. But the target of these assessments has been to clarify orders of magnitudes and not to find out detailed estimates.

The assessment shows that the beneficial economical, energy and environmental impacts (in terms of green house gases releases) of external wall refurbishments can be maximised with help of thorough and supported (with help of economic incentives or fiscal instruments) refurbishment. However, the economy of extensive renovation is typically not as good than in the case of new construction. This means that when the target is very ambiguous (like 0-energy level), this may be difficult to be achieved economically by refurbishing existing old buildings.

The environmental and economic impacts of the SUSREF Concepts can be summarised as follows:

- remarkable reduction of energy consumptions
- remarkable reduction of carbon footprint
- reasonable increase of investment cost
- relevant savings in life cycle cost
- increase of resale value.

The costs of separate refurbishment actions vary a lot in Europe. Especially the cost of 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.

Both the need and the available support for the development of refurbishment product concepts are increasing. At the same time the demand for avoiding negative health effects has to be taken into account. The increase of energy refurbishments with minor skills is a health risk in many countries.

Heating systems are moving towards decentralized and smaller solutions and the use of renewable energy sources (for example making use of wind, ground soil, water and solar energy). As the need for heating energy decreases, large energy production companies face the need for remarkable development programmes regarding the reduction of carbon foot print and changes in pricing methods.

The export businesses of companies as well as the free mobilisation of experts and labour are increasing. This makes it easier to manage the European labour policy.

Factors accelerating the refurbishment volume may be

- increase of migration
- the realization of remarkable changes in values of flats caused by refurbishments
- increase of investment supports and release of taxes by societies
- new kind of flexible contracting and financing models
- increased use of energy labelling and green image
- development and improvement of detailed refurbishment concepts and (networked) actors for segmented clients (for example social housing, house holds, owners of small houses, interior designers..)
- increased support for innovations concerning refurbishment concepts
- increase of specialization areas (for example demolishment with high rates of re-use of materials).

The most remarkable risks concern

- management of changes in energy production
- adequacy and management of movements of labour connected to timing, quality and cost demands
- management of damage mechanisms of façade structures
- possible cost and health effects of individual unsuccessful refurbishments.

The most remarkable possibilities concern

- acceleration of refurbishment innovations
- adequate training programmes of companies and labour
- new kind of financing and supporting mechanisms
- creating concepts where extensive renovations are carried out in the context of big areal refurbishment projects.

It can be estimated that the instantaneous market value of a building increases roughly in accordance with the paid costs for the refurbishment work. Naturally this will start to decrease gradually after the refurbishment. However, the more durable increase of economic value (market value) can be achieved with help of refurbishment especially when the building or the block of buildings is located in 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 in market value. This can also be realised with help of increasing the density of the area. The increased use of sustainable building classification methods may also increase the valuation of refurbished areas.

The economic assessment has traditionally been done concerning the building/apartment owner and considering the return of investment and payback times. It has been already shown that renovating a building or building part like external wall merely for the sake of energy saving is not profitable. However, when ever a renovation takes place for other reasons (ageing, damage, etc.) it is profitable to invest to gain energy savings and better indoor quality. If the economy of renovations and energy savings would be assessed on a wider scale considering the energy production and consumption and the economic impacts of reduced environmental impacts of the whole energy production, the renovation might look profitable on community level. From this point of view different kinds of economic support and stimulation measures may be very justified.

6.7 Conclusions

Europe 2020 is the EU's growth strategy for the coming decade. Sustainable growth for Europe includes:

1) building a competitive low-carbon economy that makes efficient, sustainable use of resources
2) capitalising on Europe's leadership in developing new green technologies and production methods and
3) helping consumers make well-informed sustainable choices.

The corresponding EU targets for this sustainable growth include[31]

1) Reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020. The EU is prepared to go further and reduce by 30% if other developed countries make simila
2) commitments and developing countries contribute according to their abilities, as part of a comprehensive global agreement
3) Increasing the share of renewables in final energy consumption to 20%
4) Moving towards a 20% increase in energy efficiency.

According to the EUROSTAT the building volume in Europe (EU-25) is (2002) 20.4 milliard m^2. IMPRO project assessed that the total volume of residential buildings in Europe (EU 25) is 12.6 milliard m^2 (single family buildings) and 4.45 milliard m^2 (total for multifamily buildings and high-rise buildings). They also assessed that the total energy consumption is 41 348 MJ/m^2*a (single family buildings) and 30 353 MJ/m^2*a (total for multifamily buildings and high-rise buildings).

SUSREF has 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 directed purely for the energy related refurbishment. On the other hand the savings in energy costs were assessed to be 2 500 million euro/year. On the basis of that 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 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%.

The estimated saving on GHG emissions on the basis of SUSREF concepts was 72 Mt/year.

31 http://ec.europa.eu/europe2020/priorities/sustainable-growth/index_en.htm

7 Assessment of the refurbishment of exterior walls on energy consumption of buildings

7.1 Introduction

Chapter 7 presents assessment results about the impact of building refurbishment on energy consumption on building level in different European conditions.

The work focused on the effect of façade refurbishment on building dynamics. This approach provided building-level analysis about building behaviour in terms of heating and cooling demand as well as hygrothermal behaviour of the studied facades. The resulting indoor climate was also considered.

First the pre-existing façades were studied after which the situation after facade refurbishment was analysed. Analysis focused on understanding the façade behaviour and its effects on building energy performance and indoor climate, as well as identification of key issues/locations where refurbishment technologies should be focused.

In order to estimate changes in building energy performance after façade refurbishment solutions, dynamic multi-zone simulation was used. In previous tasks, representative buildings and façade configurations were identified, as well as relevant climatic conditions. All this information was used to simulate the whole building performance.

7.2 Studied cases

The cases studied were modelled covering the most important types of exterior walls described in Chapter 2.

Construction details and other parameters of buildings other than exterior walls were properly defined according to national standards, building stock specifics, and usual building occupation.

For each country a specific climate selection was made. The climate was defined to be representative of the different countries. Priority was set to the selection of humid climates as they perform more critically regarding indoor air and building material moisture content.

For instance, the selected Spanish cases are Bilbao and Barcelona; both are coastal cities with high levels of humidity, and represent both mild Atlantic and Mediterranean climates.

In the next table, selected climates and related building typologies are plotted:

Table 56. Simulation cases.

Country	Climates	Building Types
Norway	Bergen Oslo	Detached Single family Terraced single family Multi-storey or multifamily
Finland	Tampere Helsinki	Detached Single family Multi-storey or multifamily
UK	Sheffield	Semi-detached Single family Terraced single family
Estonia	Tallinn	Detached Single family Multi-storey or multifamily
Spain	Bilbao Barcelona	Detached Single family Terraced single family Multi-storey or multifamily

7.3 Simulation guidelines

An approach was defined for the consistent performance of studies of buildings in different climates. This framework was necessary due to the high sensitivity of results depending on the assumptions made in the simulation design process.

The main scope of simulation guidelines was the fixation of the following:

- Thermal simulation tool: Energy Plus was set as the reference simulation tool.
- Considered and disregarded phenomena: Heat and moisture transfer was focused as the main goal, while other aspects were limited (HVAC, shading…) as were not considered relevant to this study. Some technical limitations or special considerations were also made regarding wind, rain, coatings, heat recovery and other issues.
- Selection of representative areas of the buildings to be modelled.
- Required output.

Depending on climatic particularities country specific variations to the modelling guidelines were considered.

7.4 Buildings simulated

High rise buildings

As the scope of this project is on façade refurbishment requirements, attention was not paid to roof and basement. For that reason, in high rise buildings, an intermediate floor were modelled, assuming that the floors above and below are identical to the modelled one.

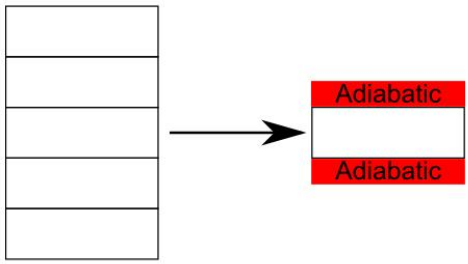


Figure 36. Adiabatic assumption in simulation.

The apartment selected for the modelling was done in the following way:

- In the case of central apartment with only one façade, only this typology (yellow) was modelled.

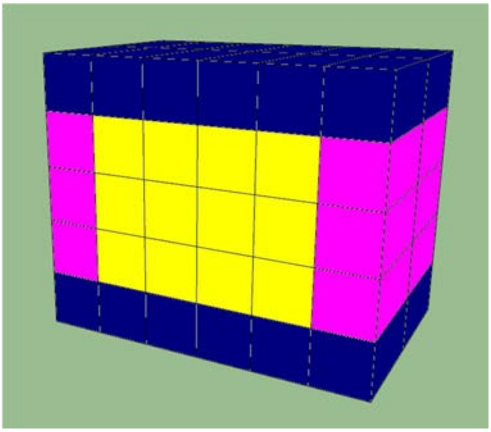


Figure 37. Principle of the apartment selection.

- In the case of no predominant apartment type, both central apartment (yellow) and side apartment (pink) were modelled.

In general, no basement or attic was modelled because those zones are not characterised by the performance of the façade.

An orientation dependant analysis was performed. This was done by rotating the building in such a way that the surface defined as "south" will alternatively be also west, north and east oriented.

HVAC

Ideal HVAC systems were used at all time. The main systems were the following:

- Heating
- Cooling
- Ventilation
- Heat recovery from exhaust air.

Heating and cooling were modelled as fully capable for providing/removing enough heat to maintain the required temperature for the building.

When heat recovery is used, the ventilation heat loss/gain is an output from the simulation. Once the heat is known, the heat recovery rate will be applied. The heat recovered in the heat recovery system will be subtracted from the heating/cooling loads.

For northern climates, cooling may not be present as it is not commonly installed in that area in residential buildings. Also, for southern climates, heat recovery devices are rare and may not be present. Heat recovery was not modelled directly in the simulation process, but in the post process phase.

Simulation Outputs

The performed analyses were focused in the following:

- Whole-building thermal analysis
- Indoor air quality analysis
- HAMT performance of the façade with a simplified approach.

The following variables were considered:

- Heating energy demand
- Cooling energy demand
- Ventilation energy losses
- Insulation properties (RH) and thermal transmittance of façade constructions
- Damage due to mould growth (EN ISO 13788:2001: RH above 80%), as a control variable for HAMT performance

- Indoor Air quality (EN 15251:2007: RH above both 60% and 70%[32] and below both 30% and 25%).

The variables can be divided to three main categories: Temperature, water content and energy needs. Depending on the case, some of those will not be necessary or complementary data was also collected. Data was collected for both HAMT and traditional (no-HAMT simulations such as CTF algorithm) models. In no-HAMT models water content variables were not considered.

7.5 Case studies Norway and Finland

This section describes the results of hygrothermal simulation of two representative building types in Norway. There were altogether three building types that were simulated in the project (detached, terraced and multi-family) but here only two building types, detached and multi-family, are presented. The results for the terraced house are close to the results of detached and multi-family houses.

The climates chosen for the analysis were Oslo and Bergen from Norway, and Helsinki and Tampere from Finland.

Refurbishment Cases

Simulations were performed for four base cases with four different external refurbishment cases (Table 57). External insulation is a preferable insulation method compared to internal insulation due to decreased available area and an increased risk for mould in the latter. Internal insulation is still used in special cases e.g. on protected buildings. Another disadvantage of internal insulation is that most thermal bridges are more easily improved by external insulation. A study of the effect of thermal mass was made in the UK case study. The refurbishments are in all cases a mineral insulation layer of 100 mm respectively 150 mm. The mineral wool comes from two different suppliers and has different **λ**-value for the detached house and the multi-family house, see Table 57.

Table 57. Simulated refurbishment cases with different λ-value.

Refurbishment ID	d [mm]	λ [W/mK]
REF 1	100	0.035
REF 2	150	0.035
REF 3	100	0.037
REF 4	150	0.037

32 UNE EN ISO 7730

The current refurbishment case applied for the wood frame wall and the multi-layer wall was made of mineral wool and has a λ-value of 0.035 W/mK. The old cladding and wind barrier are removed before fixing this flex system board with screws and plastic washers on the original wall, see Figure 69. The ability to use screws instead of a wood frame decreases the thermal bridges and thus improves the total U-value of the wall. A new wind barrier, battens and external cladding are then mounted.

Figure 38. Refurbishment by TOBB in Trondheim 2010.

The refurbishment case applied on the brick wall and concrete wall is a mineral wool board with a λ-value of 0.037 W/mK; an alternative is EPS with a λ-value of 0.038 W/mK. After removing and cleaning the original wall, the new insulation material is glued and screwed on when needed. The insulation will then be covered by a new rendering system, of scratch coat and finish coat plaster.

Simulation cases

Three cases were simulated with using Oslo climate (Table **58**). Case 2 and 3 were also simulated in Bergen (Norway) climate as well as in two climates in Finland; Helsinki and Tampere. The previous studies showed that the orientation of the house has an impact on the heating load of the houses. The effect of orientation on the refurbishment cases was studied in case 1. In case 2 and 3 the orientations having the biggest and lowest impact was chosen. The CTF-algorithm (Conduction Transfer Function) in Energy Plus was used as well as the weather data that is supplied by Energy Plus. To emphasize the results of the refurbishment of the facades, the rest of the envelope, ventilation rate and occupancy was remained unchanged. Cooling units are seldom installed in residential houses in the northern countries, wherefore no such units were simulated either in base cases or in the refurbishment cases.

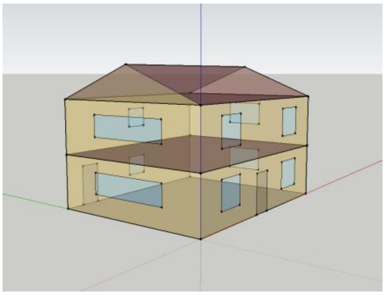
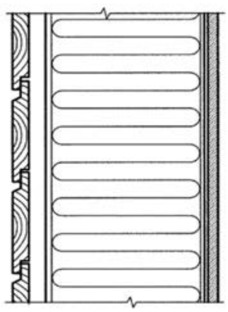
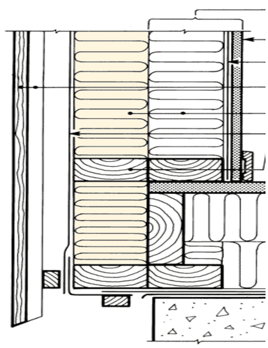
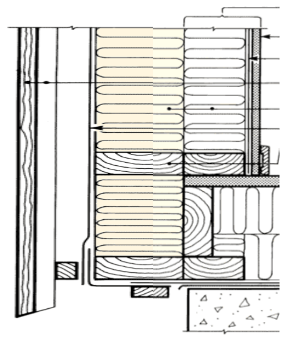
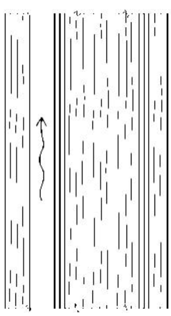
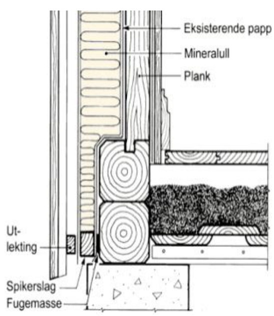
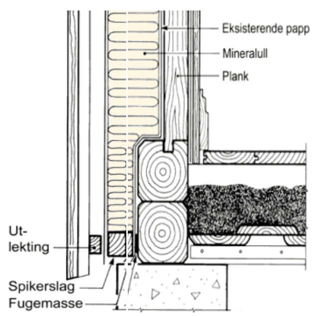
Table 58. Simulation cases.

	Case 1	Case 2	Case 3
Climates	1	4	4
Orientation	4	2	2
Facade constructions	1	2	2
Refurbishments	2	2	2
Calculation algorithms	1	1	1
Simulations cases	**8**	**32**	**32**

Case 2: Detached house

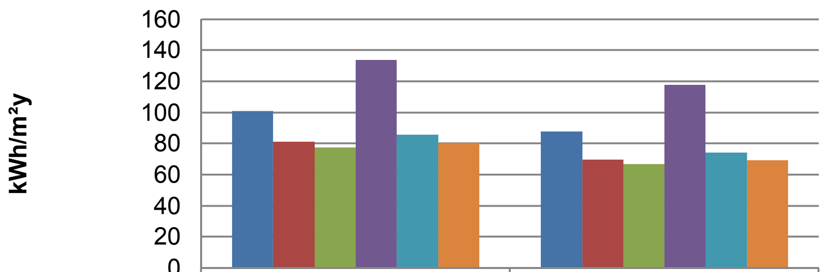
Case 2 a studied a detached house with two different facades; the wood frame wall facade (F1) which was also studied in case 1 and a multi-layer wall facade (F2) with a U-value of 0.88 W/m^{2}K. The refurbishment cases had the same facades as in case 1, with a 100 mm and a 150 mm external insulation of mineral wool with a new U-value of 0.19 or 0.15 W/m^{2}K on the wood frame wall and 0.25 or 0.19 W/m^{2}K on the multi-layer wall. The infiltration, as well as the occupancy and ventilation were constant. No sun shading was used.

Table 59. Case 2, detached house.

Case 2		
		
Original facades	Refurbishment cases	
 **F1** U = 0.42 W/m^{2}K	 **F1_REF3** U = 0.19 W/m^{2}K	 **F1_REF4** U = 0.15 W/m^{2}K
 **F2**_U = 0.88 W/m^{2}K	 **F2_REF3** U = 0.25 W/m^{2}K	 **F2_REF4** U = 0.18 W/m^{2}K

Heating loads (Norway)

The relative reduction of annual heating demand in the Norwegian cases depends marginally on the climate, whereas the refurbishment of a detached house with a wood frame facade in both Oslo and Bergen climate has a reduction of 20 % for 100 mm insulation and 23–24% for 150 mm insulation. The same refurbishment on multilayer wall gives a reduction of 36–37% or 40–41% respectively. Although the relative reduction is similar in the cases, the reduction in kWh is higher in colder climate, as well as if the original U-value, the reduction curve becomes steeper for the first refurbishment case.



	Heating load Oslo (kWh/m²y)	Heating load Bergen (kWh/m²y)
DH F1, N/S (0°)	101,1	87,8
DH F1, REF1	81,3	70,0
DH F1, REF2	77,9	67,0
DH F2, N/S (0°)	133,9	118,1
DH F2, REF1	86,0	74,5
DH F2, REF2	80,5	69,5

Figure 39. Required heating load in wood frame detached house and in multilayer detached house in Oslo and Bergen climate.

Indoor climate in Norway

The refurbishment cases of the house affect the indoor temperature. During heating season the indoor temperature only varies between the set point values 19 and 21 °C, but during the rest of the year, the temperature is higher in the refurbishment cases. The poor U-value in DH_F2 leads to a divagation in the indoor temperature in September when it still is off-heating season. As a result of the changed indoor temperature in the building, the humidity of the indoor air is lower in the refurbishment cases (Table 60). The temperature and humidity does not differ much between the two refurbishment cases. The indoor climate and humidity rate does not exceed the limit where there is a risk for mould. A closer analysis was performed in the humid climate of the Bergen case (Figure 40).

Table 60. Indoor temperature and humidity in detached house in Oslo climate, with two different facades and refurbishment cases.

Façade	**F1**			**F2**		
Orientation	N/S (0°)			N/S (0°)		
Refurbishment	Original	REF3	REF4	Original	REF3	REF4
Temperature (°C)	22.7	22.8	22.8	22.2	22.6	22.7
RH (%)	32.0	32.0	31.9	32.4	32.1	32.1

Bergen is known for having a humid climate and the indoor relative humidity is also higher than in the other simulated cases. The highest humidity appears during the summer months and fall and is higher in the multi-layer wall case (Figure 42). Comparing the temperature of the two floors in the house the upper floor always tend to have a higher temperature up to +2 °C and a lower humidity up to -2% in summer. The indoor temperature follows the outdoor temperature during the summer months where the upper floor is more influenced. Although the climate is humid, the time of wetness over 60% is not more than 260 hours and over 70% only 9 hours per year on facade 2 and it decreases in refurbishment cases. This occurs mostly during September month.

Table 61. Summary of yearly average temperature and RH and time of wetness, hours with RH over 60 and 70 % in Bergen climate.

Façade	F1						F2					
Orientation	N/S (0°)			S/N (180°)			N/S (0°)			S/N (180°)		
Refurbishment	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4
Temperature Upper Floor (°C)	21.9	21.9	22.0	21.6	21.6	21.7	21.1	21.9	22.0	20.9	21.6	21.7
RH Upper Floor (%)	36.9	36.9	36.7	37.5	37.5	37.4	37.9	36.9	36.8	38.4	37.6	37.4
Upper Floor TOW(RH > 60)	30.00	20.0	15.0	53.0	39.0	30.0	207.0	16.0	3.0	261.0	33.0	19.0
TOW(RH > 70)	0.00	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	9.0	0.0	0.0
Temperature Lower Floor (°C)	21.1	21.1	21.2	20.9	20.9	20.9	20.6	21.1	21.1	20.4	20.8	20.9
RH Lower Floor (%)	38.6	38.5	38.6	39.1	39.0	39.1	39.0	38.6	38.6	39.4	39.1	39.1
Lower Floor TOW(RH > 60)	35.0	34.0	24.0	55.0	51.0	37.0	150.0	26.0	18.0	200.0	36.0	31.0
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

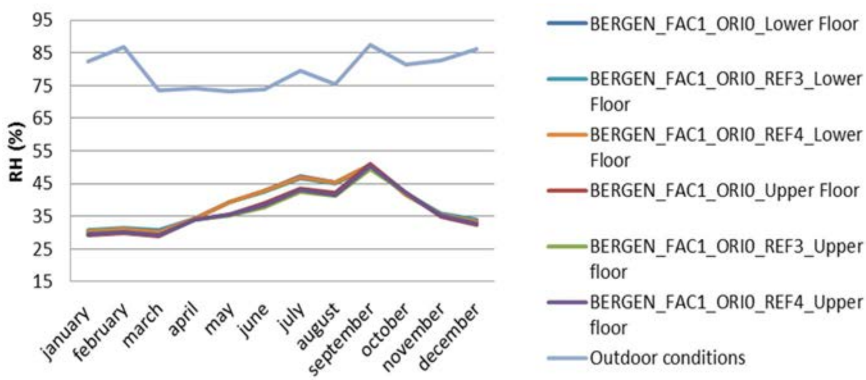


Figure 40. Monthly average RH in detached house with two refurbishment cases and the original wood frame wall (F1) and multilayer wall (F2).

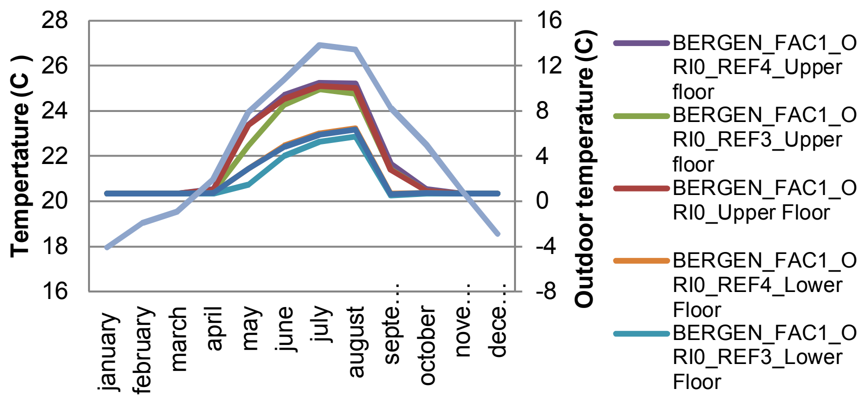


Figure 41. Monthly average indoor temperature on upper and lower floor in detached house with original wood frame wall facade (FAC 2) and two refurbishment cases.

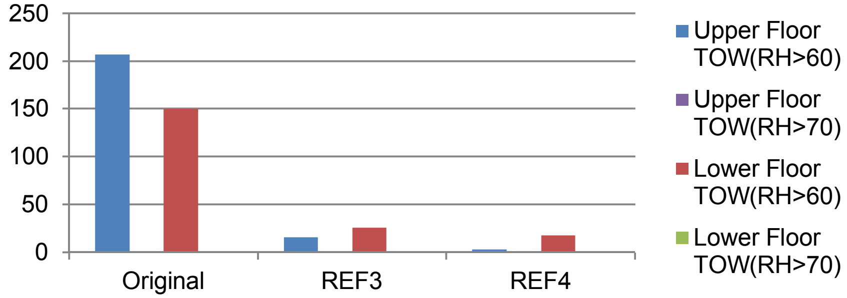


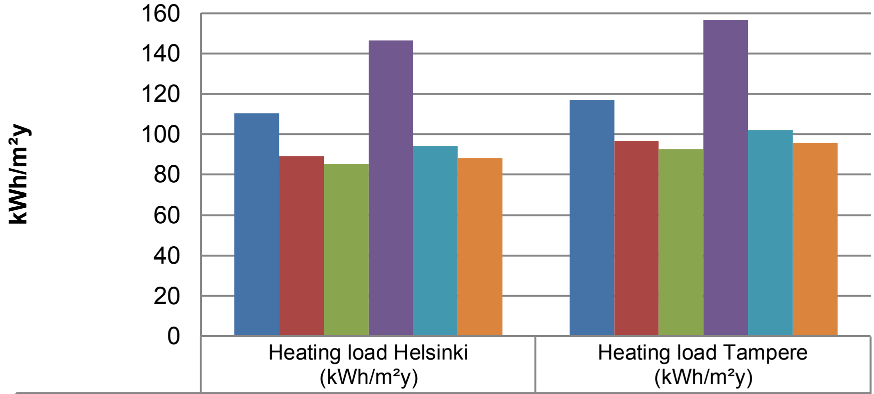
Figure 42. Yearly time of wetness in indoor air in detached house with multilayer facade.

Heating loads in Finland

The refurbishment cases for Helsinki are comparable with the one done in the Oslo climate.

Additional insulation on wood frame wall (F1) with a 100 mm respectively 150 mm exterior insulation gives a reduced annual heating demand of up to 19 and 23% in the Helsinki climate and respectively 17 or 21% for the Tampere climate (Figure 43).

Refurbishment of a multilayer wall (F2) with a 100 mm or 150 mm exterior insulation gives a reduced annual heating demand of up to 35–36 and 39–40% in Tampere and Helsinki climate.



	Heating load Helsinki (kWh/m²y)	Heating load Tampere (kWh/m²y)
DH F1, N/S (0°)	110,5	117,3
DH F1, REF1	89,2	96,8
DH F1, REF2	85,5	92,9
DH F2, N/S (0°)	146,5	156,8
DH F2, REF1	94,4	102,3
DH F2, REF2	88,4	96,0

Figure 43. Yearly heating demand. Wood frame wall and multilayer wall compared with the external refurbishment cases in Helsinki and Tampere climate.

Indoor climate in Finland

The indoor temperature in Helsinki is higher than in Bergen, with an average temperature of over 22 °C in wood frame wall house. The indoor climate in Tampere correlates with the indoor climate in Helsinki, with an average temperature of over 22 °C in the wood frame wall house and slightly lower in the lower floor.

The average indoor temperature is less than +1 °C higher in the upper floor but is up to 2 °C higher during summer (Table 62 and Table 63).

For F1, the indoor temperature and relative humidity remain the same after the refurbishment.

For F2, the indoor temperature increases slightly and with that decreases the relative humidity in the refurbishment cases. In the off-heating season, a comfort temperature is not reached during spring and autumn with the original facade, whereas the refurbishment cases can maintain a comfort temperature during these times, although in summer the average indoor temperature reaches controlled max temperature of 27 °C.

The temperature is lower and the humidity is higher in the lower floor in all the cases.

Table 62. Summary of yearly average temperature and RH and time of wetness, hours with an RH over 60 resp 70% in Helsinki climate.

Façade	F1						F2					
Orientation	N/S (0°)			E/W (180°)			N/S (0°)			E/W (180°)		
Refurbishment	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4
Temperature Upper Floor (°C)	22.4	22.5	22.6	22.1	22.2	22.3	21.9	22.4	22.5	21.6	22.1	22.2
RH Upper Floor (%)	32.1	32.0	31.9	32.7	32.7	32.6	32.8	32.2	32.1	33.4	32.8	32.8
Upper Floor TOW(RH > 60)	0.00	0.0	0.0	19.0	0.0	0.0	35.0	0.0	0.0	49.0	0.0	0.0
TOW(RH > 70)	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Temperature Lower Floor (°C)	21.6	21.7	21.7	21.3	21.3	21.4	21.2	21.6	21.6	21.0	21.3	21.3
RH Lower Floor (%)	34.0	34.1	34.0	34.6	34.7	34.7	34.3	34.2	34.1	34.8	34.8	34.8
Lower Floor TOW(RH > 60)	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	15.0	0.0	0.0
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 63. Summary of yearly average temperature and RH and time of wetness, hours with an RH over 60 resp 70% in Tampere climate.

Façade	F1						F2					
Orientation	N/S (0°)			E/W (180°)			N/S (0°)			E/W (180°)		
Refurbishment	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4	Original	REF3	REF4
Temperature Upper Floor (C°)	22.3	22.4	22.5	22.0	22.1	22.1	21.8	22.3	22.4	21.5	22.1	22.1
RH Upper Floor (%)	30.8	30.8	30.6	31.4	31.5	31.4	31.3	30.9	30.8	31.9	31.5	31.5
Upper Floor TOW(RH > 60)	4.00	0.0	0.0	13.0	8.0	0.0	33.0	0.0	0.0	42.0	8.0	0.0
TOW(RH > 70)	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Temperature Lower Floor (C°)	21.4	21.5	21.6	21.2	21.2	21.3	21.1	21.4	21.5	20.9	21.2	21.2
RH Lower Floor (%)	32.7	32.9	32.8	33.2	33.5	33.5	32.9	32.9	32.9	33.4	33.5	33.5
Lower Floor TOW(RH > 60)	0.0	0.0	0.0	8.0	7.0	4.0	15.0	0.0	0.0	17.0	7.0	0.0
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

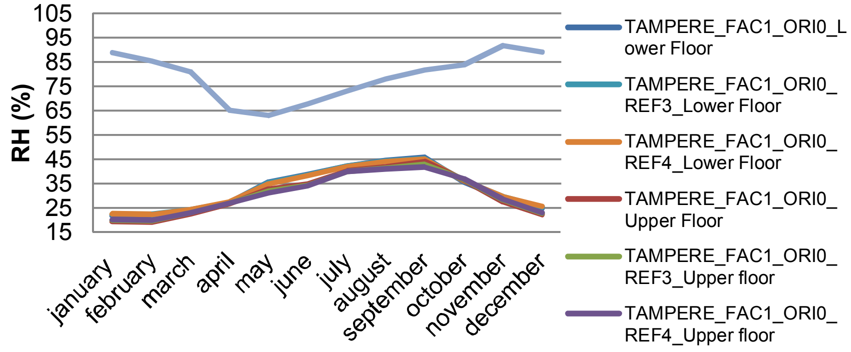


Figure 44. Monthly average RH on the upper and lower floor in a detached house with two refurbishment cases and the original wood frame wall (FAC 1).

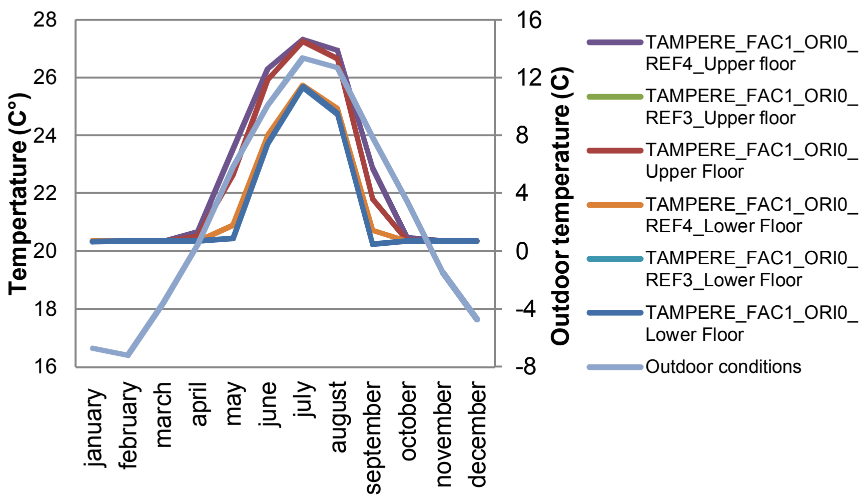
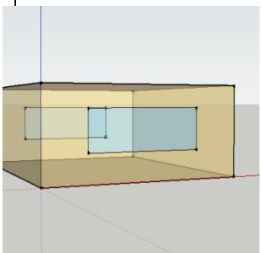
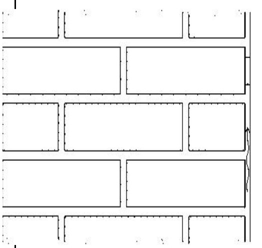
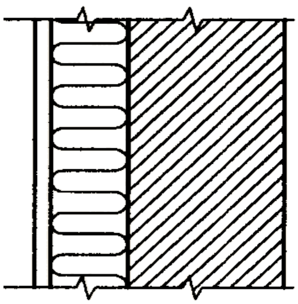
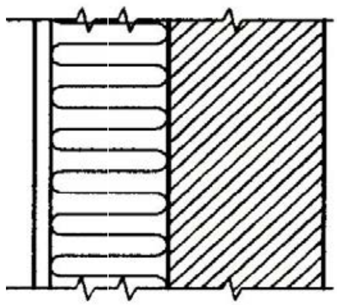
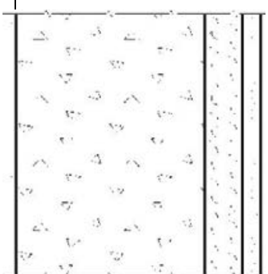
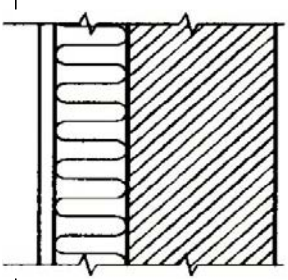
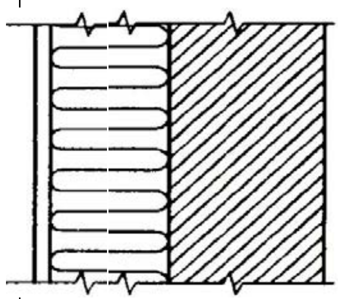


Figure 45. Monthly average indoor temperature on the upper and lower floor in a detached house with the original wood frame wall (FAC 1) and two refurbishment cases.

Case 3: Multi-family house

With regard to the multi-family house in case 3, two facades were studied. One solid brick wall (F3) with the original U-value of 0.88 W/m^{2}K. The refurbishment cases are 100 mm and 150 mm mineral wool external insulation which gives the wall a U-value of 0.26 respectively 0.19 W/m^{2}K. The second case is originally a concrete wall with a wood wool slab as an internal insulation (F4). The original wall has a U-value of 1.1 W/m^2K and with the same refurbishment cases as for F3 a new U-value of 0.28 respectively 0.20 W/m^2K is given. The infiltration will not be changed between the original facade and the refurbishment cases, though the infiltration is lower in case 3 than in case 1 and 2. The calculations on the multi-family house are concentrated on one apartment in the middle of the building with adiabatic floor and ceiling. Consequently, the only heat loss through the envelope will occur through the two facades including the windows. No sun shading is used on the building.

Table 64. Case 2, multi-family house.

2		
		
al facades	bishment cases	
		
= 0.88 W/m^{2}K	**EF3** U = 0.26 W/m^{2}K	**EF4** U = 0.19 W/m^{2}K
		
= 1.1 W/m^{2}K	**4**_REF3 U = 0.28 W/m^{2}K	**EF4** U = 0.20 W/m^{2}K

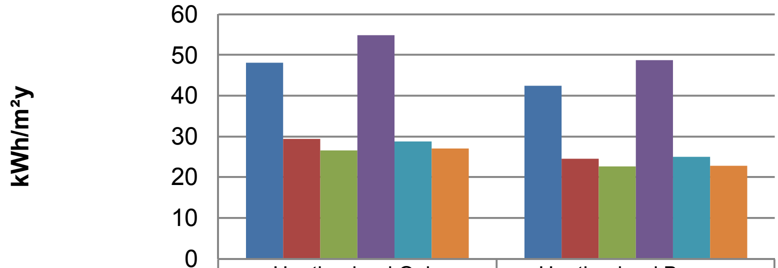
Heating loads Norway

The northern countries do not use cooling units in residential buildings. Thus the following results primary show the energy demand per square meter for the original facades as well as for the refurbishment cases. The main results are found below:

As also shown in case 1 the annual heating demands in the refurbishment cases are not dependent on the orientation when studying relative reduction.

On a brick wall (F3), a 100 mm and a 150 mm insulation refurbishment can result in an annual heating demand reduction of 39–42% and 45–47% in Oslo and respectively in Bergen climate.

An original concrete wall (F4), with a higher initial U-value, has a steeper heating demand reduction curve where a 100 mm and 150 mm insulation refurbishment can reduce up to 47–49% respectively 51–53% the annual demand (Figure 46).



	Heating load Oslo (kWh/m²y)	Heating load Bergen (kWh/m²y)
MFH F3, N/S (0°)	48,1	42,5
MFH F3, REF3	29,5	24,7
MFH F3, REF4	26,6	22,7
MFH F4, N/S (0°)	54,9	48,8
MFH F4, REF3	28,9	25,0
MFH F4, REF4	27,1	22,9

Figure 46. Yearly heating demand on a wood frame wall and a multi-layer wall compared with the external refurbishment cases in an Oslo and Bergen climate.

<u>Indoor climate in Norway</u>

The operation of heating is controlled to sustain an indoor temperature of 21 °C during the day and 19 °C during the night. During the summer months, the heating in the building is turned off. This leads to a low indoor temperature in the apartment with concrete wall facade in comparison with the brick wall facade where the temperature during the summer reaches the controlled max temperature of 27 °C.

The heating system is set to hold a good thermal comfort; the temperature during the winter months does not differ between the cases. The variation will therefore rather be seen in the heating load. Studying the case of the original concrete wall, the average indoor temperature goes under 20 °C in the off-heating season. The average temperature in this case increases with 0.5–1.0 °C in the refurbishment cases and with that the thermal comfort (Table 65 and Table 66).

Figure 48 shows the time of wetness, when the RH is higher than 60 or 70%. With the brick wall facade, the RH never goes over 60%. In the apartment with the concrete wall, the RH is over 70% 130 hours per year and over 60% 981 hours per year for the original facade and decreases for the refurbishment cases. Studying the monthly average, the high humidity occurs during the summer months, July and August, when the differences between outdoors and indoors temperature are lower and outdoors RH is quite high (see Figure 47 for further information).

The humid climate in Bergen with its cool summers contributes to a higher humidity indoors than in the other climates and the thermal comfort increases with the refurbishment cases.

For the brick wall, during the summer, the highest monthly average temperature in the refurbishment cases are 26 °C, whereas the original wall reaches 25 °C. The humidity follows the outdoor humidity during the summer but never reaches the risk areas over 60%.

For the concrete wall, during the summer, the highest monthly average temperature is reached in the refurbishment case REF4, with 21 °C, whereas the original wall has 19 °C as the lowest average temperature. The humidity is highest during the summer when the indoor temperature is low. The time of wetness over 60% is over 1200 hours in the original facade but decreases to half the time in REF3 and the same happens for REF 6.

Table 65. Summary of yearly average temperature and RH and numbers of hours with an RH over 60 resp 70 % in Oslo Bergen climate.

Façade	**F3**						**F4**					
Orientation	N/S (0°)			E/W (90°)			N/S (0°)			E/W (90°)		
Refurbishment	F3	REF3	REF4	F3	REF3	REF4	F4	REF3	REF4	F4	REF3	REF4
Temperature (°C)	22.7	22.9	23.0	22.7	22.8	22.9	20.2	20.70	21.0	20.2	20.71	21.0
RH (%)	34.0	33.6	33.4	33.9	33.5	33.4	40.3	39.65	39.1	40.2	39.55	39.1
TOW(RH > 60)	0.0	0.0	0.0	0.0	0.0	0.0	986	567	393	981	558	374
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	142	0.0	0.0	130	0.0	0.00

Table 66. Summary of yearly average temperature and RH and numbers of hours with an RH over 60 resp 70% in Bergen climate.

Facade	**F3**						**F4**					
Orientation	N/S (0°)			E/W (90°)			N/S (0°)			E/W (90°)		
Refurbishment	F3	REF3	REF4	F3	REF3	REF4	F4	REF3	REF4	F4	REF3	REF4
Temperature (°C)	21.6	22.4	22.5	21.7	22.4	22.5	19.8	20.2	20.4	19.8	20.2	20.4
RH (%)	39.3	37.6	37.3	38.9	37.5	37.3	43.5	43.2	42.9	43.5	43.2	42.9
TOW(RH > 60)	0.0	0.0	0.0	0.0	0.0	0.0	1,201	551	259	1,261	567	284
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	5.00	0.0	0.0	7.00	0.0	0.00

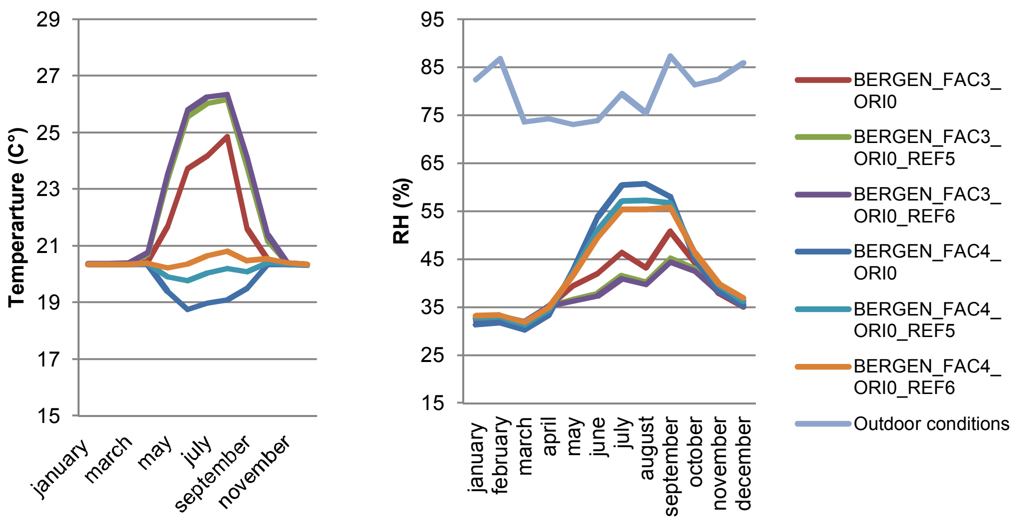


Figure 47. Monthly average indoor temperature and humidity in a multi-family house with the original facades and two refurbishment cases in Bergen climate.

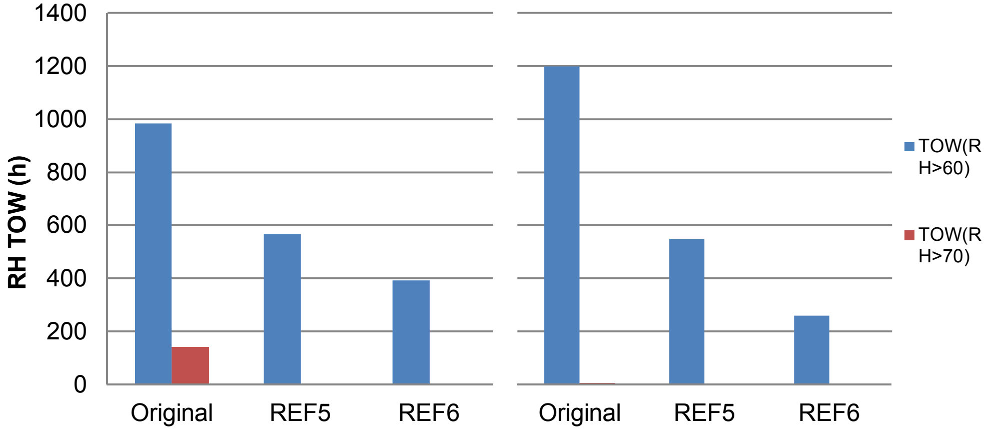


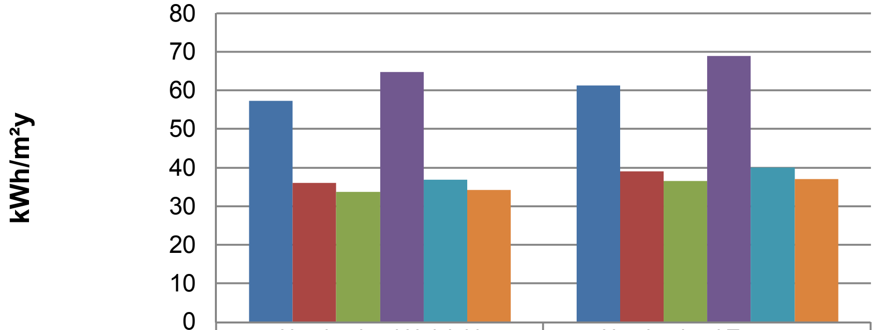
Figure 48. Yearly time of wetness over 60 respectively 70% in an apartment with an original concrete wall (F4) and two refurbishment cases in Oslo respectively Bergen climate.

Heating loads Finland

The heating loads for the Finnish cases are relatively comparable.

On a brick wall (F3), a 100 mm and a 150 mm insulation refurbishment can result in an annual heating demand reduction of up to 14% respectively 17%.

An original concrete wall (F4), with a higher initial U-value, has a steeper heating demand reduction curve where a 100 mm and 150 mm insulation refurbishment can reduce up to 40% respectively 54% of the annual demand.



	Heating load Helsinki (kWh/m²y)	Heating load Tampere (kWh/m²y)
MFH F3, N/S (0°)	57,4	61,3
MFH F3, REF3	36,2	39,2
MFH F3, REF4	33,7	36,7
MFH F4, N/S (0°)	64,8	69,0
MFH F4, REF3	36,9	40,1
MFH F4, REF4	34,2	37,2

Figure 49. Yearly heating demand on a wood frame wall and a multi-layer wall compared with the external refurbishment cases in Helsinki and Tampere climate.

<u>Indoor climate Finland</u>

The indoor temperature in Helsinki and Tampere is corresponding in all the cases. However, the monthly indoor temperature in the Helsinki refurbishment cases increases more in the off-heating season. The indoor temperature in F4 does decreases under 20 °C during the summer but not in the same range as is does in the cooler Bergen climate.

The humidity is highest during the summer when the indoor temperature is low. The time of wetness never reaches a RH over 60% in the brick wall case, but in the original concrete wall case the time of wetness (TOW) is just under or over 1000 hours in both Helsinki as Tampere climate. As in Bergen climate TOW reduces to 50% on the refurbishment case REF3 and then again in REF 6. Studying the monthly average relative humidity in Figure 51, the high humidity occurs during the summer months, July and August, when the temperature according to Figure 50 is low.

Table 67. Summary of yearly average temperature and RH and numbers of hours with an RH over 60 resp 70% in Helsinki climate.

Façade	F3						F4					
Orientation	**N/S (0°)**			**E/W (90°)**			**N/S (0°)**			**E/W (90°)**		
Refurbishment	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**
Temperature (°C)	22.6	22.8	22.9	22.5	22.8	22.8	20.1	20.65	20.9	20.1	20.63	20.9
RH (%)	33.9	33.4	33.2	33.9	33.4	33.3	40.0	39.36	38.9	40.0	39.35	38.9
TOW(RH > 60)	0.0	0.0	0.0	0.0	0.0	0.0	1,040.00	467.0	212.0	1,081.00	495.0	231.00
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	50.00	3.0	0.0	55.00	5.0	0.00

Table 68. Summary of yearly average temperature and RH and numbers of hours with an RH over 60 resp 70% in Tampere climate.

Façade	F3						F4					
Orientation	**N/S (0°)**			**E/W (90°)**			**N/S (0°)**			**E/W (90°)**		
Refurbishment	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**	**Original**	**REF3**	**REF4**
Temperature (C°)	22.4	22.7	22.8	22.3	22.6	22.7	20.1	20.62	20.9	20.1	20.63	20.9
RH (%)	32.7	32.1	32.0	32.7	32.2	32.0	38.5	37.82	37.4	38.4	37.77	37.4
TOW(RH > 60)	0.0	0.0	0.0	0.0	0.0	0.0	986.00	330.0	102.0	1,001.00	320.0	100.00
TOW(RH > 70)	0.0	0.0	0.0	0.0	0.0	0.0	18.00	0.0	0.0	19.00	0.0	0.00

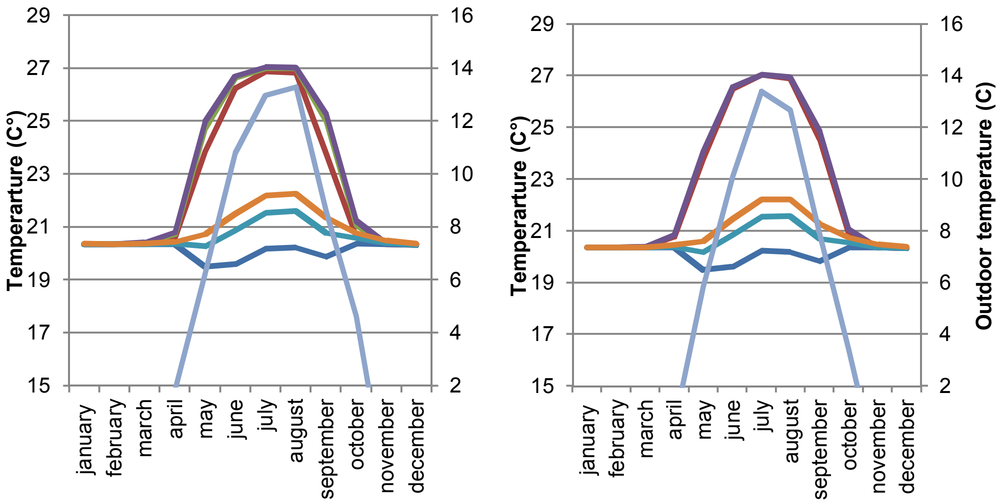


Figure 50. Monthly average indoor temperature in a multi-family house with the original facades and two refurbishment cases in Helsinki (left) and Tampere (right) climate.

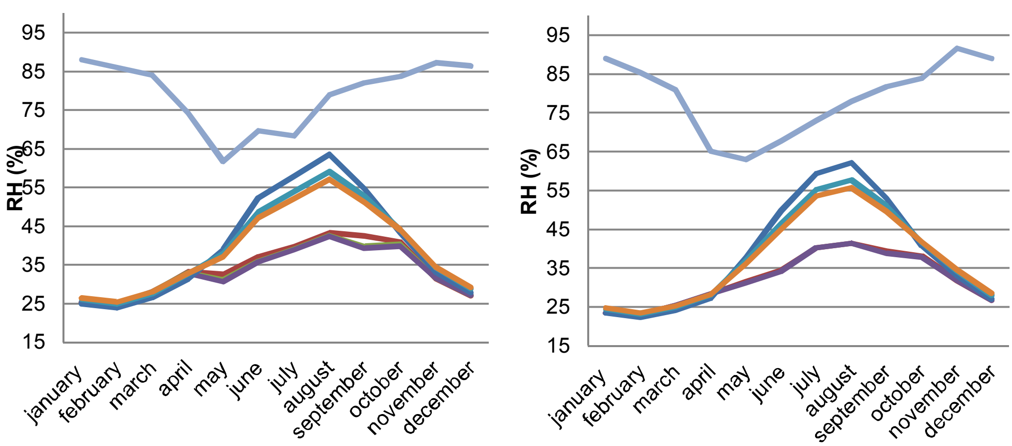


Figure 51. Monthly average relative humidity in a multi-family house with the original facades and two refurbishment cases in Helsinki (right) and Tampere (left) climate.

Discussion

Since the simulation procedures involves a lot of simplifications in comparison with a real-world situation, and involves a large number of parameter settings, it was critically reviewed the simulation results in the light of existing knowledge.

Selected results that have been compared to expected results are summarized in the following table.

Parameter	**Expected simulation outcome**	**Simulation result**	**Comment**
Indoor humidity	Moderate indoor RH in winter, high in summer. Lower with high infiltration rate and low occupancy.	Size and direction of effects as expected.	Real world results are much more variable, as moisture loads vary in time and space. Realistic distribution would require simulation of more zones and more complicated load patterns.
High RH on internal surfaces, Facades 1.2. and 3.	Short, if any, periods of high RH/internal surface condensation.	No periods with internal surface condensation.	Simulation underestimates real condensation risk severely as thermal bridges, imperfect mixing of air and effect of thermal bridges are not included in the model
Indoor temperatures	Extended periods of T > 26 °C	Extended periods of T > 26 °C	In reality moderated by solar shading and window airing not included in the model
RH in insulation (timber frame).	RH in insulation follows outdoor RH fluctuations, but values are lower in the heating season. Higher RH with lower wall U.	RH in insulation is much lower than in indoor and outdoor air, and very stable.	When internal vapour barrier is intact, indoor humidity has little impact on external wall. Air leakages and driving rain phenomena may alter picture completely.
RH in insulation (multilayer wood)	RH in insulation follows outdoor RH fluctuations closely, but values are lower. Higher RH with lower wall U.	Calculated RH in construction extremely low, with very little fluctuation	Intact internal layers normally has sufficient vapour resistance to avoid moisture buildup in insulation, indoor humidity then has little impact on external wall. Air leakages and driving rain phenomena may alter picture completely,

Parameter	Expected simulation outcome	Simulation result	Comment
RH in unconditioned zones	(RH in insulation follows outdoor RH fluctuations closely, but values are lower. Higher RH with lower floor U.)		Air leakages may lead to severe moisture problems in attics due to convections. Simulation would require treating attic as a separate, coupled zone.
Heating	Base case High infiltration Low infiltration Refurbished	Expected ranking of cases.	Several user-related phenomena can affect the actual heating use.
Cooling	Higher in refurbished solution and lo infiltration.	Refurbished solution not yet calculated. No cooling applied.	In real situations cooling would not normally be applied. User behavior, airing, screening effects, thermal mass and spatiotemporal distribution of internal gains has large impact on cooling demand, and makes simulation very complex.

Conclusion

The annual heating demand is reduced in all the refurbishment cases. The original facades with a higher U-value gain the most from the refurbishments. With more insulation or a good original U-value of the original wall, the heat loss from the other parts of the envelope restrains the effect of a measure only on the facades. This is shown in the great impact of refurbishment on the multi-family house where only one middle apartment with adiabatic roof and floor is studied. Buildings situated in colder climates also have a higher reduction of kWh than in milder climates, although the relative reduction is independent of the climate.

In the simulations no sun shades were used which increases the effect of the solar radiation and therefore also the orientation. Nevertheless, the annual heating demand reduction was not affected by the orientation in a high extent in the refurbishment cases.

Indoor temperature over 26 °C was expected and did occur during the summer, where it was frequently more common in the refurbishment cases. This could be avoided by sun shades in a real situation, though over temperature in building should not be taken lightly and will be an increased problem even in the northern countries. Indoor temperatures were consequently lower and the humidity higher in the lower floor because of the contact with the ground and the lower temperature. The low temperature can be explained as the effect of the low ground temperature. In the heating season, the temperature and humidity did not differ between the floors. Hence the high humidity depends on the indoor temperature, the outdoor humidity and the internal gains. The concrete wall facade is strongly affected by the outdoor conditions in all cases compared with the brick wall. Besides the higher original U-value, the difference in thermal mass and buffer effect give the two facades various impacts from the outdoor environment.

The table below describes the studied parameters, expectations and results.

Table 69. Studied parameters, expectations and results.

Parameter	Expected simulation outcome	Simulation result	Comment
Heating	Reduction of the energy demand in the refurbished cases.	Reduced energy demand with a negative exponential curve, depending on the original U-value.	The facades with a higher original U-value gain more by the first refurbishment.
Cooling	Higher in refurbished solution.	No cooling applied. Is shown in the indoor temperature	In real situations cooling would not normally be applied. User behavior, airing, screening effects, thermal mass and spatiotemporal distribution of internal gains has large impact on cooling demand, and makes simulation very complex.
Indoor temperatures	Extended periods of T > 26 °C. Higher temperature in the refurbished cases	Extended periods of T > 26 °C Higher temperature in the refurbished cases during the summer. Comfort temperature in the off-heating season is only reached in the refurbishment cases with FAC 4.	In reality moderated by solar shading which is not included in the model. Window airing are applied when temperature reaches 27 °C.
Indoor humidity	Moderate indoor RH in winter, high in summer. Higher in refurbished cases and in humid climates as Bergen	Lower humidity in the refurbishment cases, due to higher indoor temperature during summer. A higher humidity in a Bergen climate.	Real world results are much more variable, as moisture loads vary in time and space. Realistic distribution would require simulation of more zones and more complicated load patterns.

7.6 Case studies for Spain

This section describes results of the hygrothermal simulation of two representative building types in Spain. There were altogether three building types that were simulated in the project (detached, terraced and multi-family) but here only two building types, detached and multi-family, are presented. The results for the terraced house are close to the results of the detached and multi-family house types.

The selected climates, Bilbao and Barcelona, correspond with two coast areas in Spain (Atlantic and Mediterranean coast). Both climates are humid; however, Bilbao is cooler than Barcelona.

Refurbishment cases

Common refurbishment techniques applied for the existing façades were studied. Depending on the façade, up to four different techniques are available:

1. Traditional external insulation (EXT)
2. External insulation by adding a ventilated façade (VEN)
3. Internal insulation (INT)
4. Insulation injection on the gap of dual layered façades. (INJ).

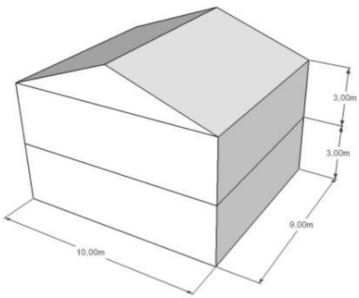
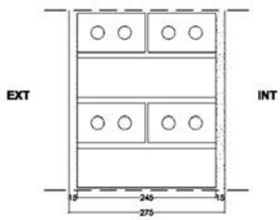
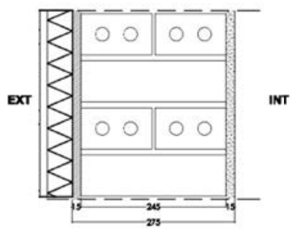
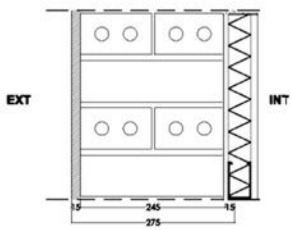
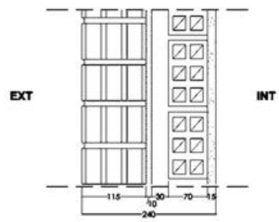
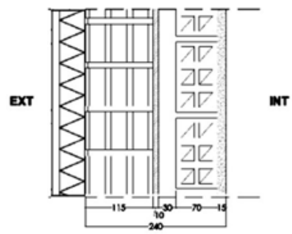
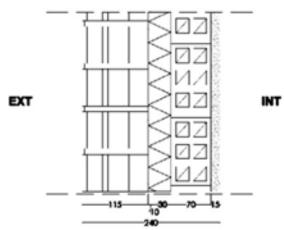
Injection refurbishment techniques are only possible in façades with pre-existing cavities, which are not previously filled with insulation (F2 and F3).

Although other refurbishment techniques are available for all façades, the addition of ventilated façades was only performed for high rise buildings (Case3), due to aesthetical issues.

The proposed refurbishment cases were selected in order to cover the proposed refurbishment techniques.

Case 1: Detached House

Table 70. Simulated cases of detached single family house.

Case 1: Sketch up	Original façade and refurbishment	Original façade and refurbishment
 	 F1_original: 1.55 W/m^{2}K  F1_EXT: 0.44 W/m^{2}K  F1_INT: 0.39 W/m^{2}K	 F2_original: 1.49 W/m^{2}K  F2_EXT: 0.45 W/m^{2}K  F2_INJ: 0.77 W/m^{2}K
Orientation	North/South (N/S) and East/West (E/W)	
Occupation	2 people/floor	
ACH	0.5	

Heating and Cooling Loads

In this section heating and cooling demand for detached two floor building have been calculated. Originally, one of the buildings' façade was a perforated brick wall (F1 with a thermal transmittance value of 1.55) and the other one was a cavity wall (F2 with an original U value of 1.49 W/m^{2}K).

Bilbao is a heating dominated climate and for this type of building, cooling regime is not important, while in Barcelona, cooling demand is higher. For each of the original façades, buildings' heating and cooling demand before and after façade refurbishment was analysed.

- For façade type 1, perforated brick wall, up to 26% (17 kWh/m^2 floor plan) of heating load reduction are achieved in Bilbao´s climate with an increase of 6 cm layer of insulation that improves the thermal transmittance from 1.55 to 0.39 W/m^{2}K[33].
- Higher reductions in absolute terms are achieved in the upper floor.
- 3 cm cavity injection reduces an average of 10 kWh/m^2 heating demand in Bilbao's weather and 6 kWh/m^2 in Barcelona's, while 6 cm of insulation can reduce up to 17 kWh/m^2.
- West/east oriented buildings energy performance is worse than south/north oriented ones, and relative and absolute reductions are slighter lower than those for south oriented, requiring additional insulation for the same heating demand reductions
- In Barcelona climate, where cooling loads are higher especially in the upper conditioned floor, insulation decreases cooling loads as well, being these reductions higher for exterior insulation.

33 Note: only transmission losses have been analyzed. No air tightness improvement after refurbishment has been analyzed. No thermal bridging effects have been analyzed for interior insulation.

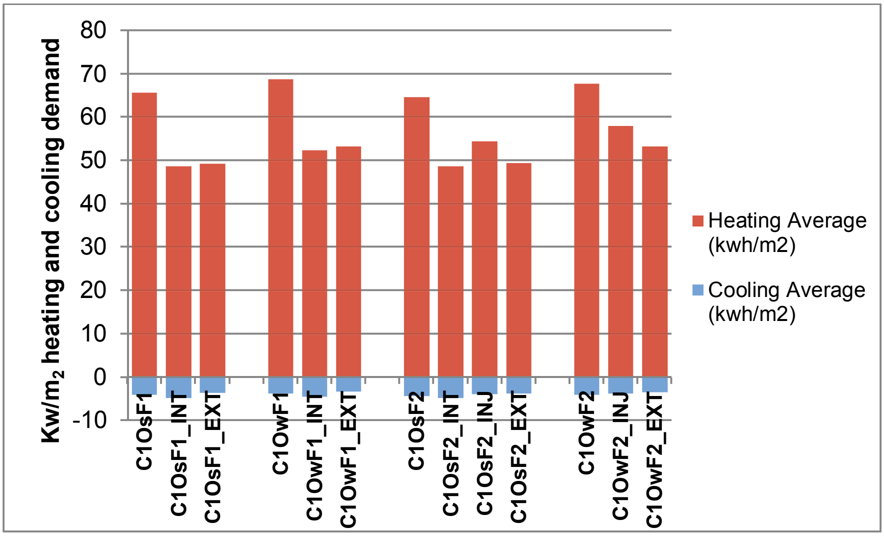


Figure 52. Heating and cooling demands per m^2 of floor-plan, in Bilbao's climate for Case 1 with Façade 1 or façade 2 before and after refurbishment. C1 represents detached individual family house; Os and Ow: south/north oriented or west/east oriented; F1: perforated brick façade; F2: double brick façade with air cavity; INT: interior insulation, EXT: exterior, INJ: insulation iinjection into cavity.

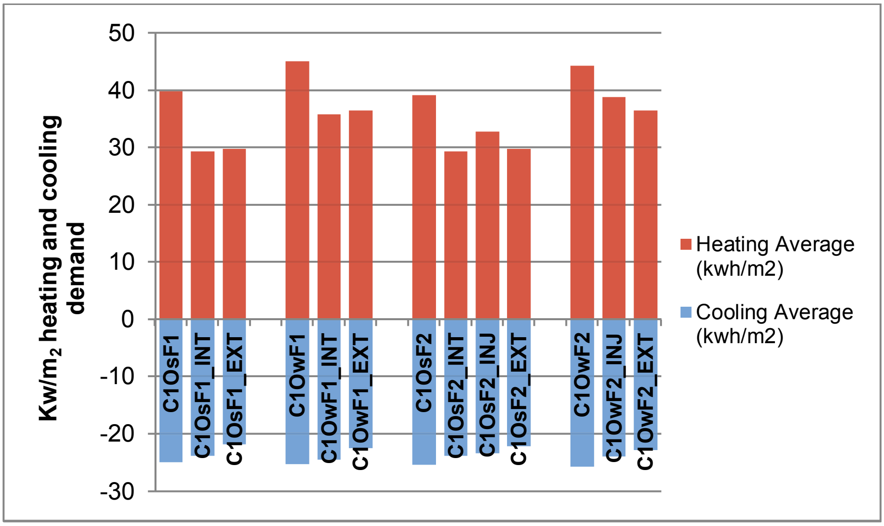


Figure 53. Heating and cooling demands per m^2 of floor-plan, in Barcelona's climate for Case 1with Façade 1 or façade 2 before and after refurbishment. C1 represents detached individual family house; Os and Ow: south/north oriented or west /east oriented; F1: perforated brick façade; F2: double brick façade with air cavity; INT: interior insulation, EXT: exterior, INJ: insulation iinjection into cavity.

<u>Indoor Climate</u>

In this section indoor climate for detached two floor buildings have been calculated. Originally, one of the buildings' façade was a perforated brick wall with a thermal transmittance of 1.55 W/m^2K (F1) and the other one's was a double brick with an air cavity wall (F2).

For each of the studied cases, the following parameters have been analyzed before and after refurbishment:

- Indoor air temperature
- Indoor air relative humidity
- Yearly number hours with zone air's RH levels higher than 60 and 70%.

The results show that indoor climate is not significantly affected. The following conclusions can be drawn:

- Indoor air's relative humidity values do not suffer major changes, for the refurbished cases, RH levels are an average of 1% lower than for the base case.
- Air zone's temperature remains within the same value range before and after refurbishment.

- Mean indoor operative temperature is an average of 0.2 °C higher in winter time for refurbished façades, and 0.1–0.2 °C lower in summer months.
- Low RH values do not represent a problem in mild climates, while higher air RH take place in the lower zone, having between 500–700 h with RH levels higher than 70%, while upper zone has around 300 h in Bilbao's weather and around 100 h in Barcelona.

The previously mentioned behaviour is observed both for Bilbao and Barcelona, while values are slightly different (lower zone air's mean temperatures and higher RH values in Bilbao).

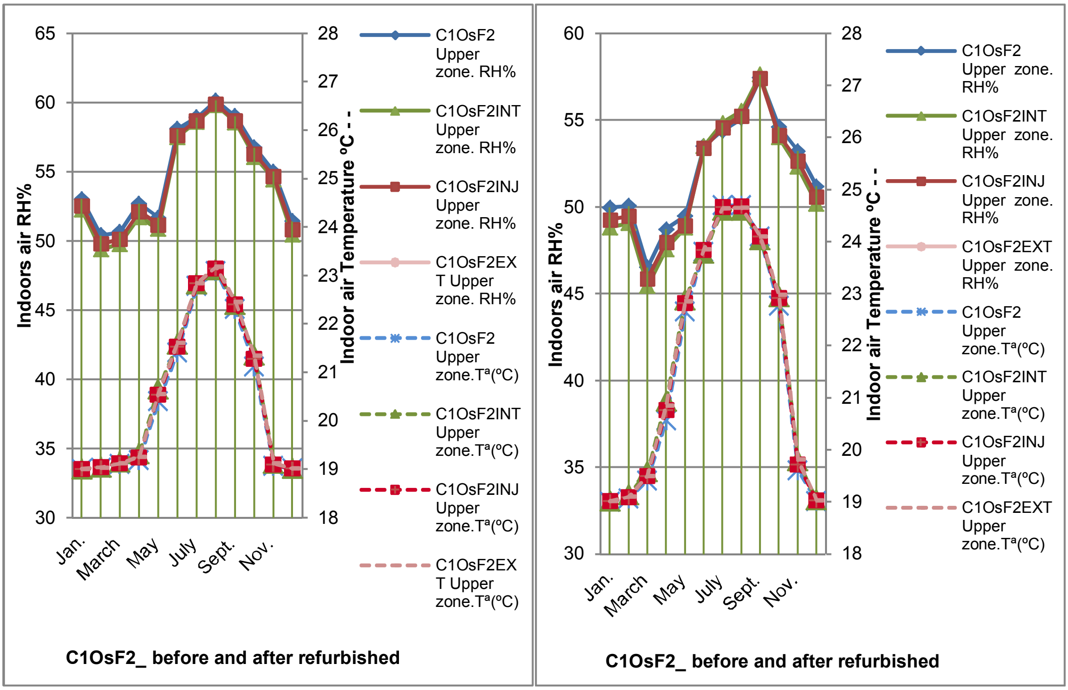
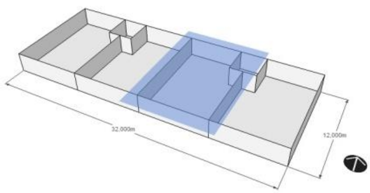
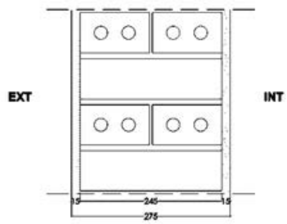
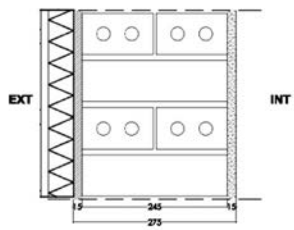
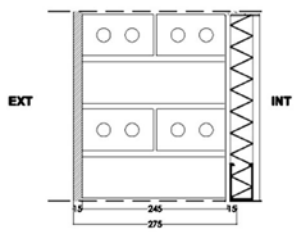
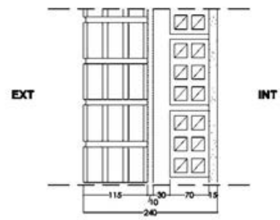
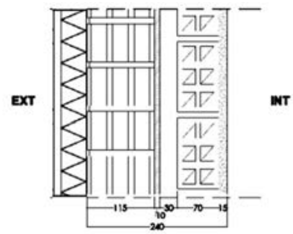
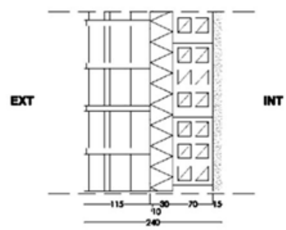


Figure 54. Bilbao's and Barcelona´s indoor climate – relative humidity of air, indoor air temperature, and operative temperature – for Case 1, before and after refurbishment with interior or exterior insulation practices.

<u>Case 3: Multi Storey Flat</u>

Table 71. Simulated cases of terraced house.

Case 1: Sketch up	Original façade and refurbishment	Original façade and refurbishment
	 **F1_original: 1.55 W/m^{2}K**  **F1_EXT: 0.44 W/m^{2}K**  **F1_INT: 0.39 W/m^{2}K**	 **F2_original: 1.49 W/m^{2}K**  **F2_EXT: 0.45 W/m^{2}K**  **F2_INJ: 0.77 W/m^{2}K**
Orientation	**N, S, E and W**	
Occupation	**2 people/floor**	
ACH	**0.5**	

<u>Heating and Cooling Loads</u>

In this section, heating and cooling demands for multi-storey or high-rise buildings are presented. Originally, one of the buildings' façade was a perforated brick wall with a thermal transmittance of 1.55 (F1) and the other one a double brick façade with an air cavity, and with a thermal transmittance value of 1.49 W/m^{2}K (F2).

As shown in previous tables, the building has two exposed façades, and the rest have been considered as adiabatic walls.

As well as for Cases 1 and 2 interior (INT), exterior (EXT) and insulation injection in the cavity (INJ) have been used as refurbishment solutions.

For each of the studied cases, buildings' heating and cooling demand after façade refurbishment are shown and compared with the original building's demand. The main results of this case can be summarized as follows:

- Refurbished solutions reduces heating demand in 8 Kwh/m^2 for façade type 1 (1.55 W/m^2K) and for west/east oriented dwellings in Bilbao's weather. Reducing heating demand from 24.6 to 16.3 kWh/m^2 [34]
- Cooling demands are also reduced with the increase of insulation levels in the façades, being for the studied cases, higher with external insulation.
- For those southern European climate zones with prevailing cooling loads, an increase in insulation will benefit the cooling load reduction, especially for exterior refurbishment.

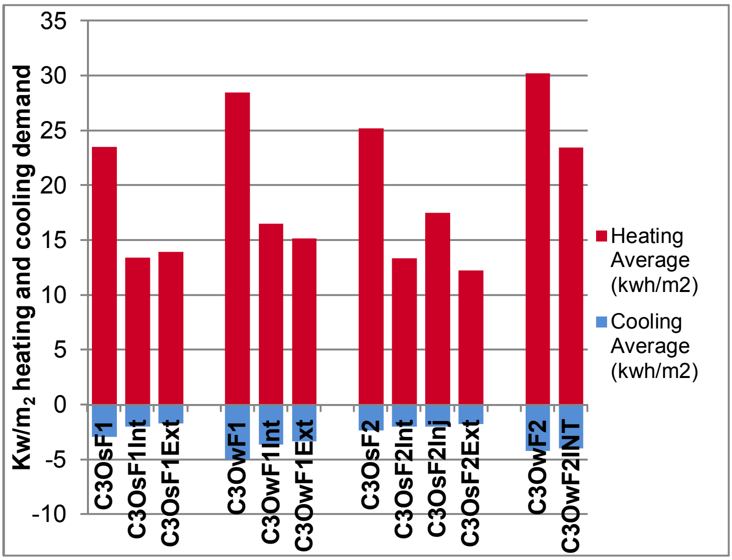


Figure 55. Heating and cooling demands per m^2 of floor-plan, in Bilbao's climate for Case 3 the multifamily house with Façade 1 before and after refurbishment with interior (INT) and exterior (EXT) refurbishment solutions. And case 3 with façade 2 before and after refurbishment with interior (INT), cavity insulation injection (INJ).

34 Note: air infiltration rate before and after refurbishment has maintained constant at 0.5 ACH.

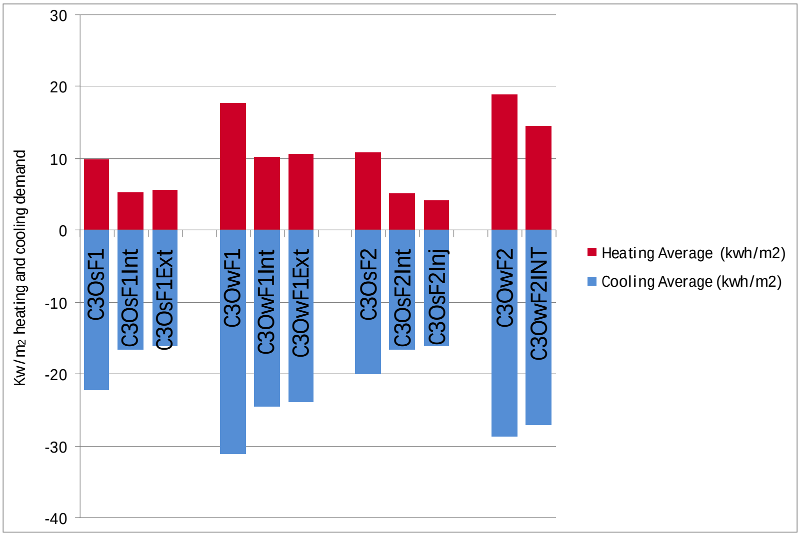


Figure 56. Heating and cooling demands per m^2 of floor-plan, in Barcelona's climate for Case 3 the multifamily house with Façade 1 before and after refurbishment with interior (INT) and exterior (EXT) refurbishment solutions. And case 3 with façade 2 before and after refurbishment with interior (INT), cavity insulation injection (INJ).

Indoor Climate

In this section, the calculation results for indoor climate for detached two floor buildings are shown. Originally, one of the buildings' façade was a perforated brick wall with a thermal transmittance of 1.55 W/m^{2}K (F1) and the other one's was a double brick with an air cavity wall (F2).

For each of the studied cases, the following parameters were analysed before and after refurbishment:

- Indoor air temperature
- Indoor air relative humidity
- Yearly number hours with zone air's RH levels higher than 60 and 70%.

From the analysis of the results, the following results can be pointed out:

- Zone air's RH levels in winter decrease 5% after refurbishment.
- Zone air's temperature increases in winter months an average of 0.1 °C, while in summer months is reduced in 0.1 °C compared to the base case.
- Zone's operative temperature increases in winter months an average of 0.3 °C, and while in summer months is reduced in 0.2 °C compared to the base case, increasing thus indoor confort.

- Low RH values do not represent a problem in mild climates, while higher air RH are reached in 300 h in Bilbao and around 100 h in Barcelona.

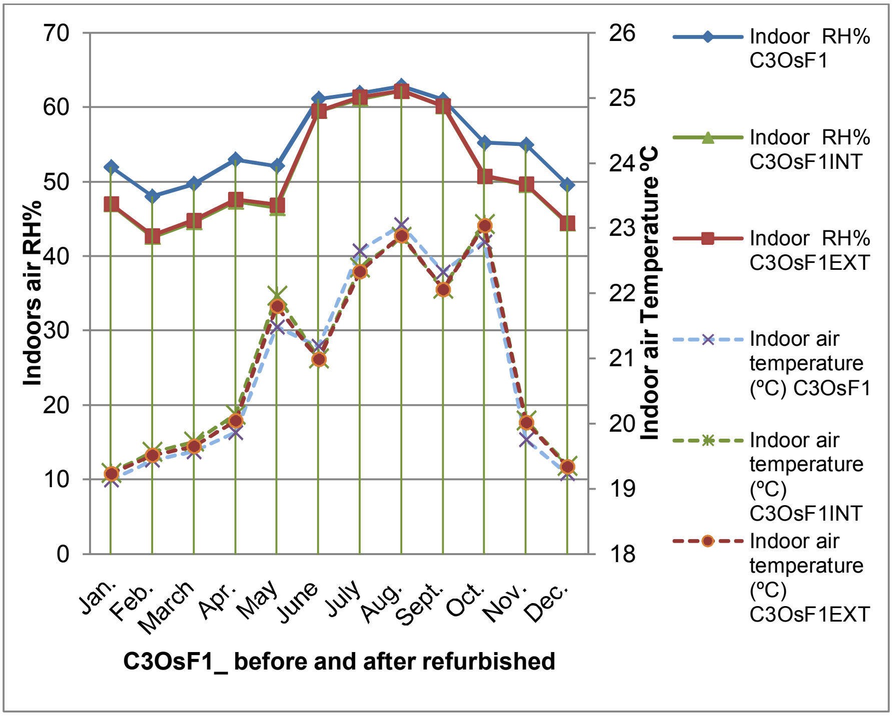


Figure 57. Bilbao's indoor climate – relative humidity of air, indoor air temperature, sum of hours with air RH – higher than 60 or 70% – for Case 3, with interior, exterior or insulation injection in cavity refurbishment practices.

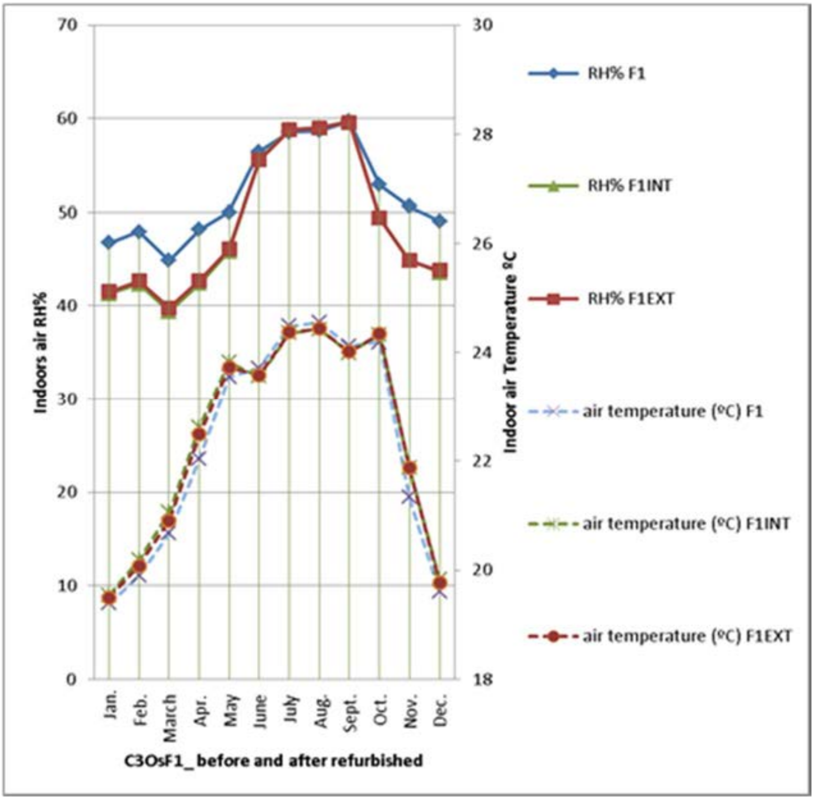


Figure 58. Barcelona's indoor climate – relative humidity of air, indoor air temperature, sum of hours with air RH – higher than 60 or 70% – for Case 3, with interior, exterior or insulation injection in cavity refurbishment practices.

<u>Discussion</u>

Table 72. Expected and actual simulation results for selected parameters.

Parameter	Expected simulation outcome	Simulation result	Comment
Indoor humidity	High indoor RH in winter and summer.	Size and direction of effects as expected.	Real world results are much more variable, as moisture loads vary in time and space. Realistic distribution would require simulation of more complicated load patterns.
High RH on	Short, if any, periods	No periods with	Simulation

Parameter	**Expected simulation outcome**	**Simulation result**	**Comment**
internal surfaces, Facades 1,2. and 3.	of high RH/internal surface condensation.	internal surface condensation.	underestimates real condensation risk severely as thermal bridges, imperfect mixing of air and complex building use patterns are not included in the model
Indoor temperatures	Extended periods of T > 26 °C	Extended periods of T > 26 °C	In reality moderated by solar shading and window airing not included in the model
RH in unconditioned zones	(RH in insulation follows outdoor RH fluctuations closely, but values are lower. Higher RH with lower floor U.)		Air leakages may lead to severe moisture problems in attics due to convections. Simulation would require treating attic as a separate, coupled zone.
Heating	Base case High infiltration Low infiltration Refurbished	Expected ranking of cases.	Several user-related phenomena can affect the actual heating use.
Cooling	For southern european countrie, lower cooling demands are expected in refurbished solution	Refurbished solution not yet calculated. No cooling applied.	In real situations cooling would not normally be applied in Bilbao climate. User behavior, airing, screening effects, thermal mass and distribution of internal gains has large impact on cooling demand, and makes simulation more complex.

Conclusions

Opaque façade insulation reduces significantly heating loads (20 kWh/m^2) especially for those existing façades with higher U values. Reductions are lowered to 2 kWh/m^2 for an existing wall with a thermal transmittance of 0.63 W/m^{2}K that is improved to 0.28 W/m^{2}K.[35]

35 No air tightness improvement due to façade rehabilitation has been analysed. Infiltration rate has kept constant to 0.5 ACH before and after refurbishment.

3 cm cavity injection reduces heating demand in Bilbao's weather in average by 10 kWh/m^2 and 6 kWh/m^2 in Barcelona, while for the same base case, 6 cm of insulation can reduce up to 17 kWh/m^2 (26% of the original case).

West/east oriented buildings' energy performance is worse than south/north oriented ones, and relative and absolute reductions are slighter lower than those for south oriented, requiring additional insulation for the same heating demand reductions.

Higher reductions in absolute terms are achieved in the upper floor, more affected for the roof. Ground floor, in contact with the terrain, is more stable.

Major reductions would have been expected if air-tightness improvement had been considered.

On the other hand, and for the analysed cases exterior insulation reduces cooling loads by preventing heat absorption in the outside walls and entering inside, reducing thus cooling loads for climates such as Barcelona.

In Barcelona climate, where cooling loads are higher especially in the upper conditioned floor, insulation decreases cooling loads as well, being these reductions higher for exterior insulation techniques.

Observations:

- Studied single family house is a two-floor building with an unoccupied attic. According to the existing building stock, the lower floor is usually in direct contact with the ground. In these cases the upper zone's heating loads, under moderately ventilated roof zone are higher than in the stories above. And for cooling demanding climatic zones, upper zones have higher cooling loads than lower zone because of the influence of the non-insulated roof.
- Relative humidity values of indoor air are higher in the lower floor than in the upper zone.
- Moisture content of indoor air is higher in summer time, because the external temperature supports higher humidity. In winter heating is on, reduces indoor air relative humidity.
- Bilbao is a heating dominated climate, whilst cooling loads are not very significant. Cooling loads become important for Mediterranean regions such as Barcelona.
- Heating are the prevailing loads for low rise buildings in contact with the terrain, while cooling loads become more important for high rise buildings.
- In the South European zones humidity levels of internal surfaces are maintained below mould growth relative humidity levels.
- The calculation methods used in moisture content calculation in walls are not sufficient for detecting issues such as humid locations near thermal bridges. The validity of the results obtained is limited to those façade areas located far from windows, corners, façade-embedded structure or other cool points.

7.7 Case studies for UK

Overview of the performed study

The most common building types in housing stock in the UK were studied. This ensures that a true representation of the largest section of the UK housing stock is achieved. The following issues were considered:

- Building geometry
- Construction elements: Envelope, roof, windows, floor structure and base
- Usage: occupancy, internal loads, etc.

During the modelling of buildings, certain limitations were identified; Design Builder does not incorporate the HAMT algorithms and therefore the CTF outputs are the only ones which were used in this study.

The climatic region chosen to model the UK situation is taken from the algorithms used in the software for demonstrating compliance with the Building Regulations in the UK, known as SAP, the Standard Assessment Procedure, the software was created by the BRE and uses the BREDEM (Building Research Establishment Domestic Energy Model), this has been in place since the early 1990's. The software and assumptions made within the calculation procedure has also been used to define the usage patterns in the energy modelling. In the UK this usage pattern is known as the normalisation factor, which is used to ensure that reported carbon savings and energy consumption is measured in the same way in any location throughout the UK, this methodology is used for the new build and refurbishment market.

A number of different factors are taken into account, including building construction, heating systems and controls, and location.

Building Types Modelled

For the UK stock three representative typologies were used:

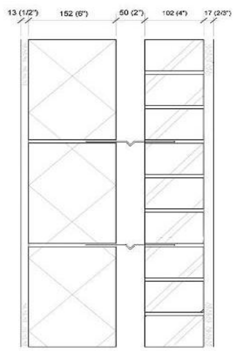
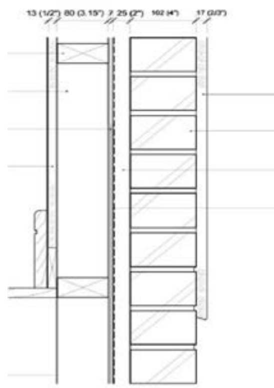
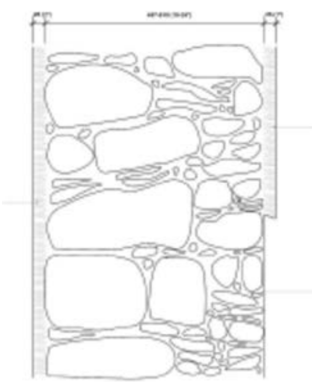
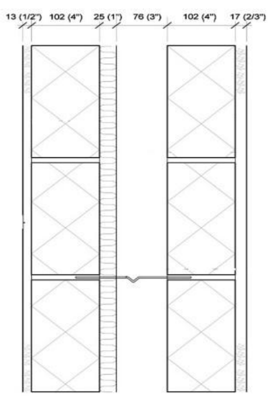
- Terraced property with solid wall constructed circa 1920 – [36]
- Semi-detached property with cavity wall construction constructed circa 1930 – [37]
- Multi-Family Units constructed circa 1960 – [38].

36 ImproBuilding (Environmental Improvement Potential of Residential Buildings (IMPRO-Building) FP7 EUR 23493 EN-2008) reference number Z2_SI_002

37 ImproBuilding reference number Z2_SI_001

38 Impro Building reference number Z2_MF_003

Table 73. Simulated cases UK.

CASE 1	**CASE 2**	**CASE 3**
Sketch		
		
façade construction types		
F1_U = 2.40 W/m^{2}K	**F3**_U = 1,6 W/m^{2}K	**F5**_U = 1,50 W/m^{2}K
		
F2_U = 2.40 W/m^{2}K	**F4**_U = 1,6 W/m^{2}K	
		

Refurbishment Case studies

The earlier study showed the analysis of base-line cases of the existing typologies in UK's climate context. In the next study improvements in the building fabric are made and the resultant reductions in the energy demand and the effect of the indoor air quality are analysed. The improvement in building fabric is made by considering wall insulation. Insulation on the walls of the dwelling can be done externally as well as internally. There are certain disadvantages in both application types of insulation specifically in old housing stock. If the insulation is done externally it comprises on the traditional look of the facades. Certain shape and forms of the dwelling and its openings also make it impractical to apply the insulation externally. If the insulation is done internally it compromises on the available floor area of the dwelling already quiet restricted in traditional housing types. In this study however an initial analysis on the effects on the thermal performance of the building fabric and consequent effect on energy demands would determine whether the insulation should be applied internally or externally. The initial analysis is tried on Case 1.

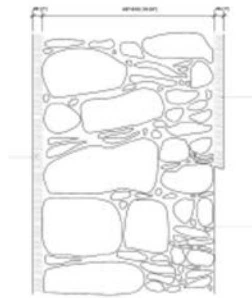
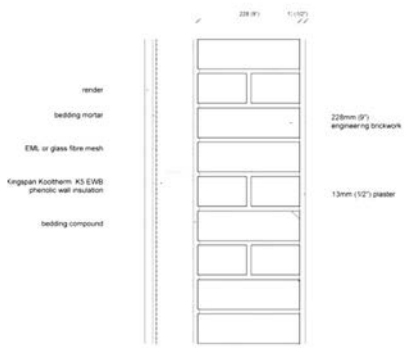
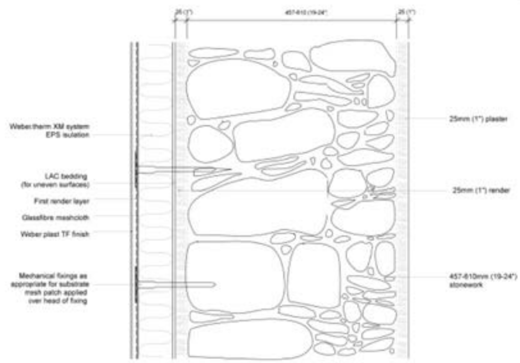
Building Fabric Improvements

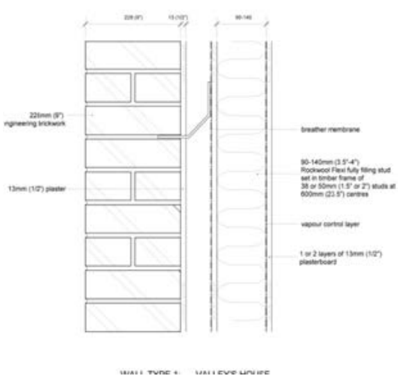
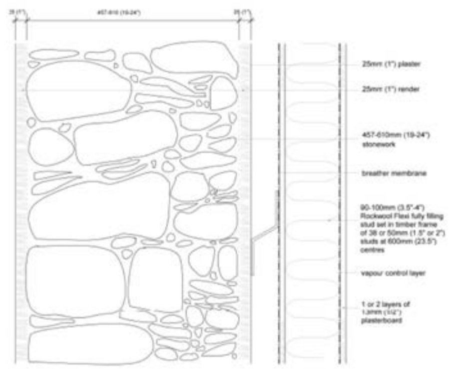
The U-value of the building fabric is reduced to 0.35 W/m^2 K, this is the figure currently required by the Building Regulations in the UK when undertaking any major refurbishment works to existing properties. The insulation is applied externally and internally in two separate models of case 1 and the resultant effect on the energy demand is analysed.

To indicate the improvements that have been made the figure below indicates the original construction form, and the new layers (indicated in blue) that have been modelled to demonstrate the method used to improve the façade thermal performance. No other elements have been improved in the modelling of these buildings, all other thermal elements such as; roof, windows, or floor have been improved to ensure that only the improvements of the walls are indicated.

To reflect the most commonly replicated construction type it has been decided to model in Case Study 1 the solid brickwork wall with improvements to the thermal performance. The random stone wall construction is one of those being field tested in Wales and will be reported on in another WP of this study. Both wall construction types would use the same methodology for improving the thermal performance.

Table 74. Studied case. Both of these wall types are typical and representative of the UK Building Stock, the construction indicated on the left is the one used in the modelling undertaken.

Current façade detail: **Solid Clay Brick**	**Random Stone and Boulder**
	
U = 2.40 W/(m²K) **Applied Insulation** External insulation	**U = 2.40 W/(m²K)** **Applied Insulation** External insulation
	
U = 0.35 W/(m²K) **Applied Insulation** Internal insulation	**U = 0.35 W/(m²K)** **Applied Insulation** Internal insulation

 **$U = 0.35\ W/(m^2K)$**	 **$U = 0.35\ W/(m^2K)$**

Two different methods of insulating external faceds are commonly used in the UK, these being internal and externally applied insulation. Although both details are indicated in the table above, the solid brick wall is the one indicated in the performed modelling work. Both internal and external methods are represented in the results.

Case 1: Terraced building with solid brick wall

The following figure shows a comparative graph of the energy demand of the case 1 typology for baseline, external wall insulation and internal wall insulation models.

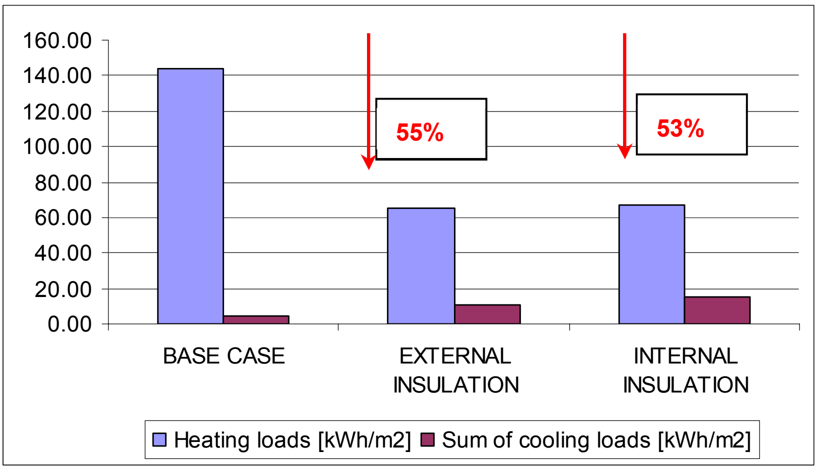


Figure 59. Heating and cooling demand before and after refurbishment for a terraced house, with solid brick walls.

Using the insulation externally on a solid wall reduced the annual heating demand by 55% as compared to 53% by using internal wall insulation. The U-value of the fabric remains independent of the location of insulation. The insulation, whether external or internal, reduces the heat loss through the walls.

The improved performance (2%) of external insulation is attributed to the 'thermal-mass effect' of the solid wall. Any solid wall (brick/ stone) acts as thermal mass storing and releasing heat after a time period called thermal time-lag of the material. The thermal time-lag is a characteristic property depending on the conductivity of the material. By adding the insulation externally the thermal mass is isolated from the outdoor environment and retains the excess heat from the inside in case the space gets overheated. When the internal ambient temperature of the space drops the stored heat is then released by the mass. The thermal mass effect reduces the energy demand of the dwelling by meeting a part of it passively.

Internal insulation of the wall blocks the benefit of the thermal mass effect. In this case the heat exchange of the thermal mass occurs with the outside.

The cooling demand however almost doubles when insulation is added, however the difference is small as compared to the effect on heating loads.

Therefore, as good practice, the external wall insulation is considered for all the cases and the effect on the energy demands and indoor air quality are analysed.

Indoor Air Quality

Ambient Air Temperature

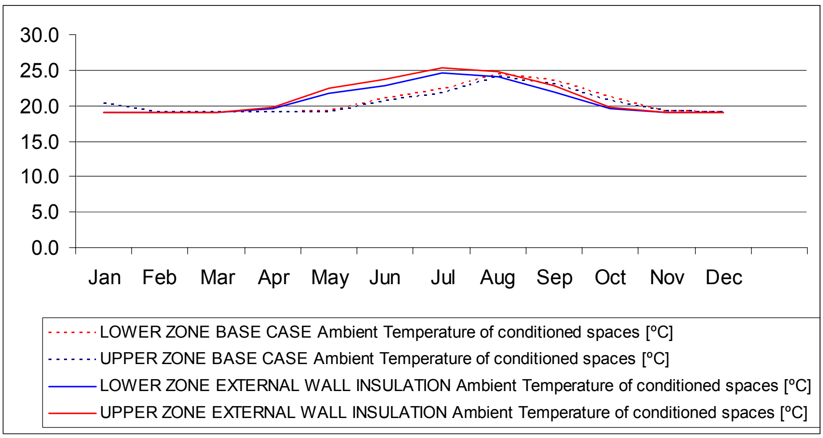


Figure 60. Mean Indoor air temperature (°C) monthly evolution.

The indoor air temperatures are lowered by 0.5–1 °C in winter and rises by approximately 2 °C in the summer months, causing an increase in the cooling demand. Hence the indoor ambient temperatures remain unaffected by adding insulation.

Humidity

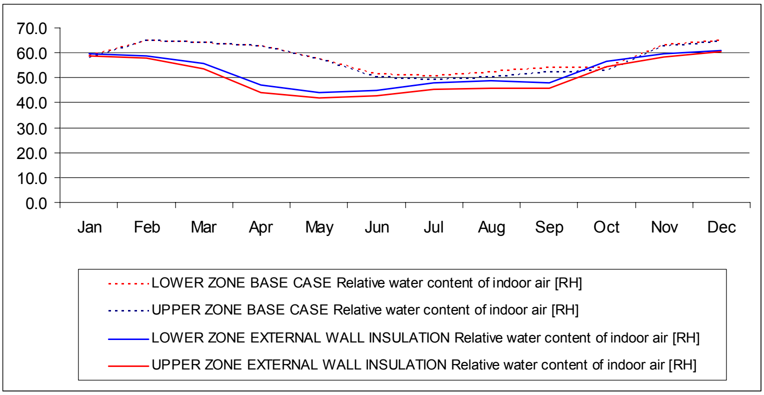


Figure 61. Mean Indoor air RH(%) monthly evolution.

The relative humidity of the indoor air is reduced considerably by 10–12% by adding wall insulation externally for the months from March-June. Higher humidity levels during heating season are due to moisture release of gas boiler.

Case 3: Multi Family Unit

<u>Heating And Cooling Loads</u>

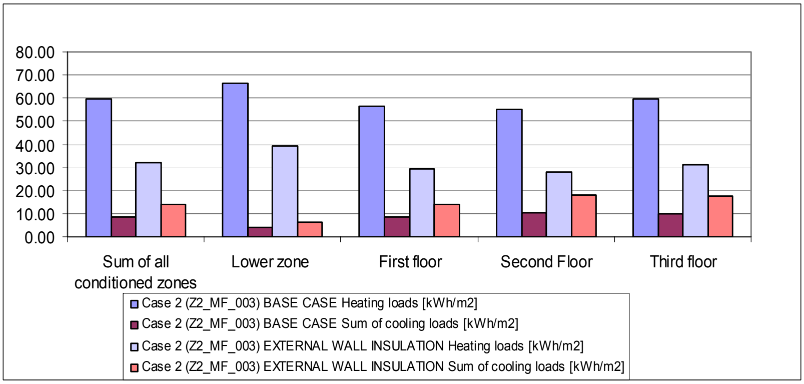


Figure 62. Heating and cooling demmands for multifamily house with brick walls before and after refurbishment with external insulation.

The previous figure shows the comparative analysis of the heating and cooling loads for base case against external wall insulation. In this case the annual heating demand reduces by 46% for the dwelling. The heating demand of the lower zone, first, second and third floor reduces by 46%, 41%, 48%, 50% and 48% respectively.

Indoor Air Quality

Temperature

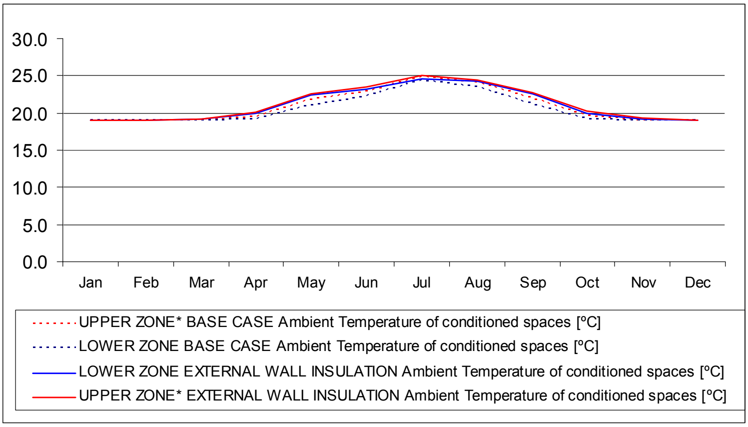


Figure 63. Mean Indoor air temperature (°C) monthly evolution in a multifamily house, before and after refurbishment with exterior insulation.

During the summer months, adding insulation increases the internal air temperatures by 1–2 °C. The internal air temperatures after adding insulation are more consistent for both upper and lower zones of the dwelling.

Humidity

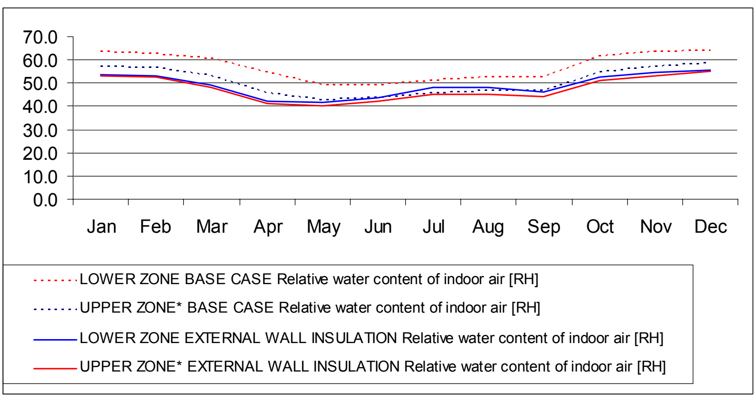


Figure 64. Mean Indoor air RH(%) monthly evolution.

The RH of the Indoor air reduces by 8–10% by adding external wall insulation. Also in this case the RH remains consistent through both lower and upper zone whereas there an approximately 5% difference in RH for upper and lower zones for the baseline scenario.

Conclusions for the UK cases

The introduction of insulation into the building during refurbishment not only improved the thermal comfort temperatures, but also delivers a more consistent range of indoor air humidity. The improvement measures have been restricted to just the fabric (external façade) to demonstrate the importance of improving the U-values and subsequent thermal performance of the wall as part of any refurbishment, although there may be many barriers to achieving this.

The results clearly show that by using the insulation on the outside of the wall the cooling load is no affected and the RH of the inside of the building is stabilized. By placing the insulation on the inside of the wall, effectively decoupling the thermal mass there is an indicated rise in the cooling load in all building types during the summer months.

Table 75. Summary of the UK cases.

Parameter	**Expected simulation outcome**	**Simulation result**	**Comment**
Indoor humidity	Higher levels of indoor humidity are expected due to the limitations in the software dealing with domestic refurbishment	As expected a Higher than anticipated level is predicted. But the introduction of insulation has dropped the level to below 60%	Is felt to be down to the unrealistic parameters set by the software, these are not considered to be realistic in the field
High RH on internal surfaces	Design Builder does not use the algorithms within Energy Plus so no conclusion can be drawn on this output		
Indoor temperatures	Higher more consistent indoor air temperatures are anticipated due to increased thermal performance	The indoor air temperature as anticipated now becomes more consistent and lays within the expected comfort zone of between 18 and 21 °C	Better internal thermal comfort levels delivered.

Parameter	Expected simulation outcome	Simulation result	Comment
RH in insulation.	Design Builder does not use the algorithms within Energy Plus so no conclusion can be drawn on this output		

7.8 Case studies for Estonia

The aim of the study was to explore the heating behaviour before any refurbishment work, for the most common buildings typologies in Estonia,

The most representative building types in Estonian building stock were selected based on:

- Building geometry
- Construction elements: Envelope (façade, roof, windows), floor structure and base
- Building use: occupancy, internal loads, etc.

The heating demand analysis was performed with Design Builder.

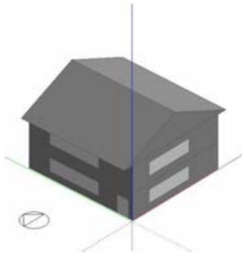
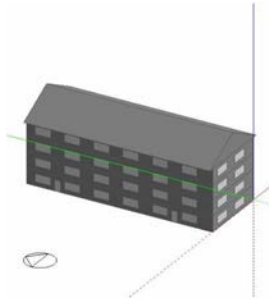
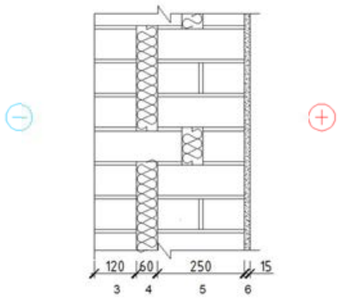
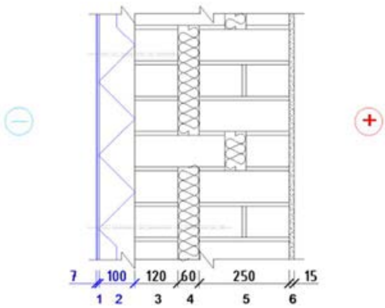
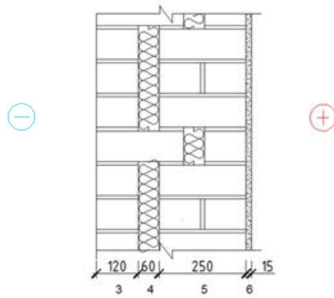
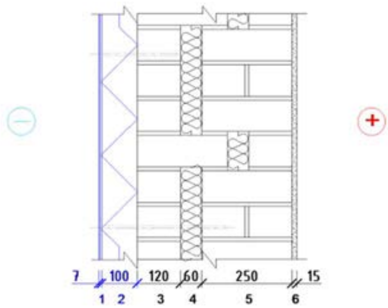
<u>Refurbishment Cases</u>

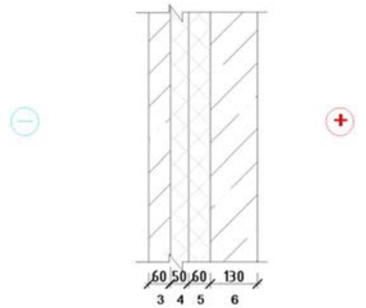
Two building typologies were considered for detached single house and multifamily house. Four wall types were considered as base cases for Estonian building stock:

- Sand lime brick wall
- Concrete sandwich panel
- Expanded clay lightweight concrete
- And gas silicate big block.

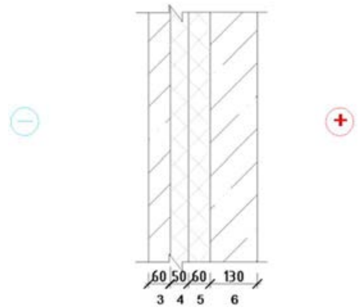
Energy performance before and after wall refurbishment of a dwelling type in Tallinn has been evaluated for eight cases. Besides energy performance, indoor air relative humidity and indoor air evolution have been studied as well. Exterior insulation is the refurbishment concept that has been used to carry out this study. Different cases are described in the following table.

Table 76. Refurbishment cases, Estonia.

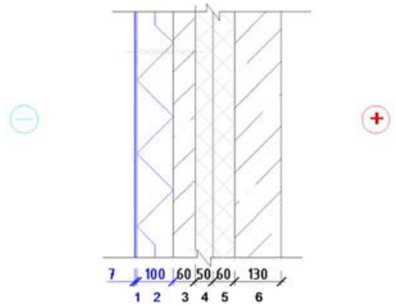
CASE 1: Single family house	**CASE2: Multi-family house**
	
 W3-2: Sand lime brick **U-VALUE: 0.7249 W/m^{2}K**  W3-2 EXT U-value: 0.2529 W/m^{2}K	 W3-2: Sand lime brick **U-VALUE: 0.7249 W/m^{2}K**  W3-2 EXT U-value:0-.2529 W/m^{2}K



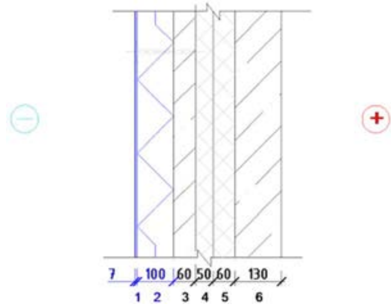
W2-1: Concrete sandwhich panel
U-VALUE: 0.543 W/m^{2}K



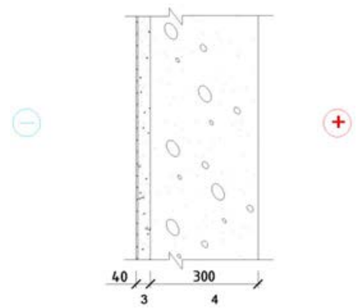
W2-1: Concrete sandwhich panel
U-VALUE: 0.543 W/m^{2}K



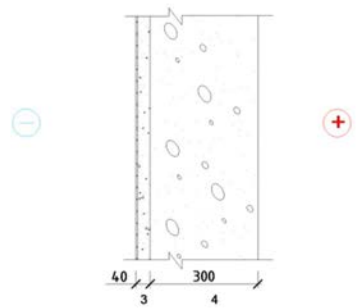
W2-1 EXT:
U-value: 0.2264 W/m^{2}K



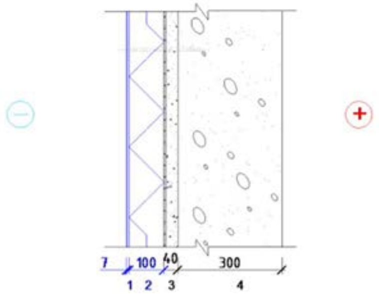
W2-1 EXT:
U-value: 0.2264 W/m^{2}K



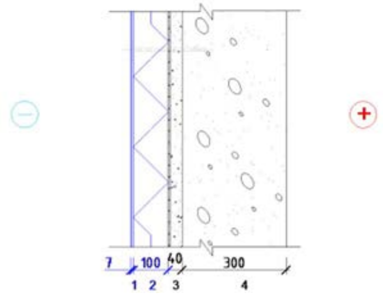
W1-1: Expanded clay lightweight concrete
U-VALUE: 1.062 W/m^{2}K



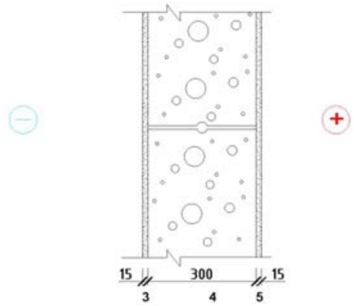
W1-1: Expanded clay lightweight concrete
U-VALUE: 1.062 W/m^{2}K



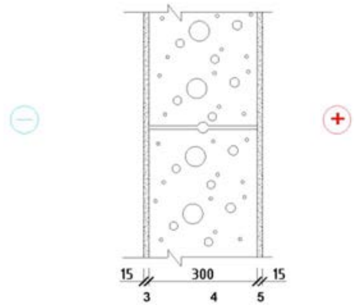
W1-EXT:
U-value: 0.284 W/m²K



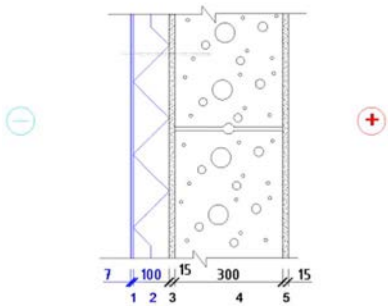
W1-1 EXT:
U-value: 0.284 W/m²K



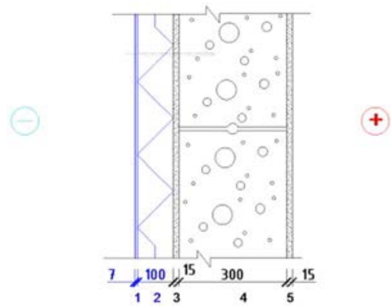
W4-1: Gas silicate big block
U-*VALUE: 1.071 W/m²K*



W4-1: Gas silicate big block
U-VALUE: 1.071 W/m²K



W4-1 EXT:
U-VALUE: 0.285 W/m²K



W4-1 External insulation
U-VALUE: 0.285 W/m²K

CASE 1: Detached Single House

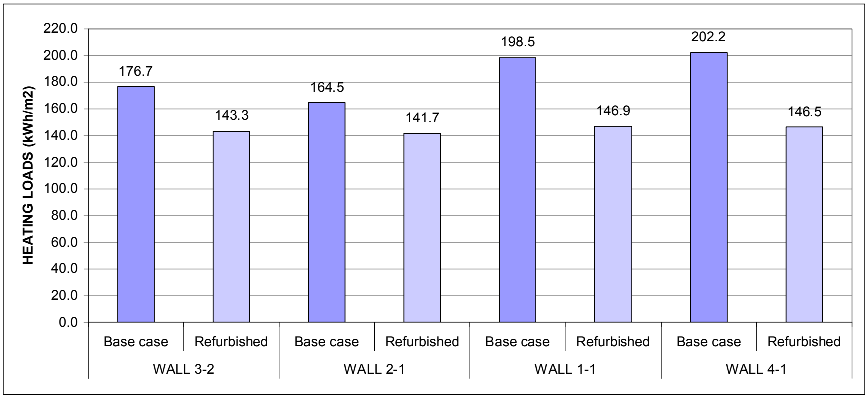


Figure 65. Heating demands for multi-family house with different walls before and after refurbishment with external insulation. Wall 3-2: sand lime brick, wall 2-1: concrete panel sandwich, wall 1-1: expanded clay lightweight concrete, wall 4-1: gas silicate big block.

The figure above shows the summary of results for the single family house using different external wall types. Maximum reduction in heating loads is shown for wall type 1-1 and 4-1 since their U-values are improved dramatically by reducing it by 73% for each wall type.

Improved insulation increases cooling energy demand by 1.5–3.6 kWh/m^2 which is insignificant compared to the decreases of the heating energy demand.

External wall type 3-2: when the U-value is improved by lowering it by 65% (by adding external insulation), the annual heating load of the building decreases by 19%.

External wall type 2-1: when the U-value is improved by lowering it by 58% (by adding external insulation), the annual heating load of the building decreases by 14%.

External wall type 1-1: when the U-value is improved by lowering it by 73% (by adding external insulation), the annual heating load of the building decreases by 26%.

External wall type 4-1: when the U-value is improved by lowering it by 72% (by adding external insulation), the annual heating load of the building decreases by 28%.

CASE 2: Multifamily House

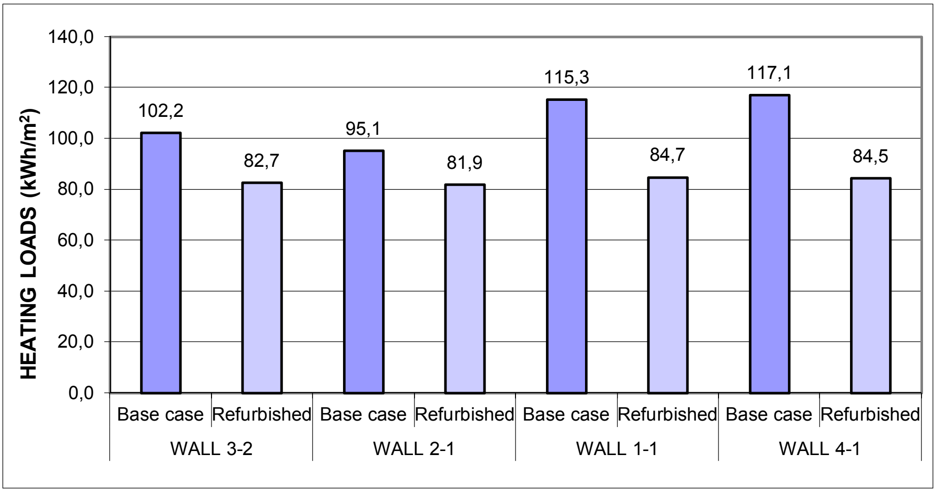


Figure 66. Heating energy demand for multifamily house with brick walls before and after refurbishment with external insulation. Wall 3-2: sand lime brick, wall 2-1: concrete panel sandwich, wall 1-1: expanded clay lightweight concrete, wall 4-1: gas silicate big block.

The previous figure shows the summary of results for the multifamily housing using different external wall types. Maximum reduction in heating loads is shown by wall type 1-1 and 4-1 since their U-values are improved dramatically by reducing it by 73% for each wall type.

Extra insulation increases cooling energy demand by 1.6–3.8 kWh/m^2 which is insignificant compared to the decreases of the heating energy demand.

External wall type 3-2: when the U-value is improved by lowering it by 65% (by adding external insulation), the annual heating load of the building decreases by 20%.

External wall type 2-1: when the U-value is improved by lowering it by 58% (by adding external insulation), the annual heating load of the building decreases by 14%.

External wall type 1-1: when the U-value is improved by lowering it by 73% (by adding external insulation), the annual heating load of the building decreases by 27%.

External wall type 4-1: when the U-value is improved by lowering it by 72% (by adding external insulation), the annual heating load of the building decreases by 28%. The result of this wall type is quiet similar to Wall type 1-1 as the U-values for base case and refurbished are similar for different construction materials.

7.9 Summary

The following findings were made on the basis of the sensitivity analysis (base case analysis) of buildings energy performance with different parameter values:

- Algorithm: though HAMT and CTF algorithms follow the same patterns, algorithms differ in their numerical results. CTF is a very robust algorithm. HAMT may lead to unexpected results, especially for low rise buildings, that's why finally CTF algorithm has been used for simulations.
- Heating demands are sensitive to building typologies, orientation and façade type. Studied climates are heating dominated climates, except for the Case 3 – multifamily dwelling – in Barcelona, with higher cooling loads than heating.
- Simulations for each of the climates have been performed with their most common façade typologies (including glazings, roofs, basement...) and therefoer, simulation results are not directly comparable.
- The simulation is set up with rather high solar transmittance factor and no shading of windows, which increases the effect of different solar irradiation, and thus reduces heating loads and increases indoor air temperatures and cooling loads in summer
- In the simulations performed for northern European countries, it is demonstrated that infiltration rates have a significant impact on internal temperature, humidity and heating demand. Simulations for UK and Spain have been done with an infiltration rate of 0.5 ACH which is quite good for an old building that needs to be refurbished. Since this factor is often hard to control in practice, it is important to vary this factor in future simulations of refurbished solutions.
- Lower RH values are achieved in winter, while higher values take place in summer. RH that fall below 30% (lower comfort values) take place in winter time in Northern European countries. These conditions do not represent a problem in southern European countries. While higher indoor RH values (higher than 70%), take place in Bilbao and Barcelona – Southern maritime European countries-.
- In buildings in contact with the terrain, moisture content of indoor air is higher in the lower floor than in the upper zone.
- The calculation methods used in moisture content calculation in walls is not sufficient for detecting issues such as humid locations near thermal bridges. The validity of the results obtained is limited to those façade areas located far from windows, corners, façade-embedded structure.
- The influence of occupancy levels was evaluated Influence on heating and cooling rates is negligible, but internal moisture content is considerably higher when building occupation rate is increased.

The energy efficiency improvement measures have been restricted to just the fabric (external façade) to demonstrate the importance of improving the U values and subsequent thermal performance of the wall as part of any refurbishment, although there may be many barriers to achieving this. The energy simulations performed after walls refurbishment with interior insulation, insulation injection in the pre-existing air chamber, exterior insulation or ventilated façade, resulted in the followings findings:

- The annual heating demand is reduced in all the refurbishment cases. The original facades with a higher U-value gain the most from the refurbishments. With more insulation or a good original U-value of the original wall, the heat loss from the other parts of the envelope restrains the effect of a measure only on the facades. This is shown in the great impact of refurbishment on the multi-family house where only one middle apartment with adiabatic roof and floor is studied. Buildings situated in colder climates also have a higher reduction of kWh than in milder climates.
- Increases on level of insulation on façade without acting on the slab and roof in one or two floor buildings, have lower effect on building's energy demand, since the energy flows through the rest of the envelope elements are increased, partially offsetting the reduction obtained for the improvement of the opaque façade. Therefore, major reductions are observed for the high-rise building typology.
- Major reductions would have been expected if air-tightness improvement had been considered.
- Greater differences would have been appreciated in heating demand reductions between interior and exterior refurbishment practices if thermal bridge had been considered in interior refurbishment practices.
- In the simulations no sun shades were used which increases the effect of the solar radiation and therefore also the orientation. Nevertheless the annual heating demand reduction was not affected by the orientation in a high extent in the refurbishment cases.
- On the other hand, and for the Southern European analysed climates, exterior insulation reduces cooling loads by preventing heat absorption in the outside walls and entering inside, reducing thus cooling loads for climates such as Barcelona, where outdoors' air mean temperature in July and August is 19 °C.
- But in climates such as UK, and with and existing massive wall, it has been seen that by placing the insulation on the inside of the wall, effectively decoupling the thermal mass there is an indicated rise in the cooling load in all building types during the summer months. While by using the insulation on the outside of the wall the cooling load is no affected and the RH of the inside of the building is stabilized.
- In heating season, indoor air temperature is set by heating set point before and after refurbishment but refurbishment increases indoor operative temperatures improving the indoor thermal comfort.

- In summer time in southern European countries where cooling loads may represent a problem, monthly mean air temperatures are on average 0.2 °C lower after building refurbishment, though instant values have more variability depending on the base façade. In northern European countries, indoor air temperatures are increased on average 0.3 °C.
- In Northern European countries low relative humidity levels (lower than 30%) may represent a problem in winter time, but no major differences have been appreciated before and after refurbishment with the performed simulations. Higher RH levels do occur in summer, when temperature differences between outdoors and indoors are small and outside RH levels are high. Time with higher RH is generally reduced in Northern Europe after refurbishment because of higher indoor air temperatures in off heating season, whilst this tendency is not replicated in Southern Europe, and time with higher RH levels are affected by the façade typology. This high humidity levels may represent a problem if façades are not dried effectively before winter (or temperature drops).

8 Recommendations for processes management, building industry, standardisation bodies and for policy makers

This Chapter gives guidelines and recommendations for processes management, building industry, standardisation bodies and for policy makers. The Chapter also describes the SUSREF tools available on the web-page of the project.

8.1 Guidelines for the management of sustainable processes

8.1.1 Introduction

Refurbishment projects are usually initiated either to satisfy a recognized need, technical condition or a requirement for improved functional performance. Improving the early planning stages for the refurbishment process, taking into account local requirements from society (aesthetic, reduced energy demand and environmental impact), the owner and users, should help to optimize performance requirements that need to be fulfilled during the process. The complexity of refurbishment processes in different countries suggests they might benefit from a comparative analysis to inform the development of a simplified framework to aid planning a decision making. The purpose of this task, therefore, is to analyse typical cases of refurbishment projects and extract from these useful information about how to organize refurbishment projects.

So, for example, the way the planning and decision making is organised, how the different stakeholders are involved in the process as well as how the different consultants, architects etc. are paid (forms of contracts) are decisive for the total results (Prupim 2011).

This Section introduces a generic framework for carrying out refurbishment of existing buildings to improve their energy and environmental performance, with particular emphasis on the refurbishment of facades.

The specific objectives of the task were:

1. To develop a generic framework for carrying out refurbishment of existing buildings to improve their energy and environmental performance, with particular emphasis on the refurbishment of facades.
2. To identify the stakeholders involved in the delivery of refurbished facades.
3. To identify the key performance indicators (KPIs) that can be used to determine the success of refurbishment projects.
4. To identify and explain the role of the various stakeholders involved in the refurbishment programme.
5. To highlight the processes of refurbishment and the contractual and other mechanisms that bind the stakeholders to the processes.

8.1.2 Refurbishment project stages

The most common reference model for the stages in a building project, particularly when an architect is involved, is the RIBA Plan of Work (RIBA 2010). This provides a detailed outline with instructions for the main tasks to be carried out at each stage. Although this has been developed for the UK and represents the procurement process from the architect's viewpoint, it has been widely adopted as framework for decision making and for deciding fees for architects and others. The stages are described below.

RIBA Plan of Work

All commissions	
1.1	Receive client's instructions
1.2	Advise client on the need to obtain statutory approvals and of the duties of the Client under the CDM regulations
1.3	Receive information about the site from the Client (CDM Reg 11)
1.4	Where applicable co-operate with and pass information to the Planning Supervisor
1.5	Visit the site and carry out an initial appraisal
A	**Appraisal**
1	Carry out studies to determine the feasibility of the Client's requirement
2A	Review with client alternative design and construction approaches and the cost implications or
2B	Provide information for report on cost implications
B	**Strategic Brief**
1	Receive strategic brief prepared by the client
C	**Outline Proposals**
1	Commence development of Strategic Brief into Project Brief
2	Prepare Outline Proposal
3A	Provide an approximation of construction costs or

3B	Provide information for cost planning
4	Obtain Client approval to Outline Proposals and approximate construction cost
5	Co-operate with Planning Supervisor where applicable
D	**Detailed Proposals**
1	Complete developments of Project Brief
2	Develop the Detailed Proposal from approved Outline Proposals
3A	Prepare a cost estimate or
3B	Provide information for preparation of cost estimate
4	Consult statutory authorities
5	Obtain Client approval to the Detailed Proposal showing spatial arrangements, material and appearance, and a cost estimate
6	Prepare and submit application for full planning permission
E	**Final Proposals**
1	Design Final Proposals from approved Detailed Proposals
2A	Revise cost estimate
2B	Provide information for revision of cost estimate
3	Consult statutory authorities on developed design proposals
4	Obtain Client approval to type of construction, quality of materials, standard of workmanship and revised cost estimate
5	Advise on consequences of any subsequent changes on cost and programme
F	**Production Information**
1	Prepare production information for tender purposes
2A	Prepare schedules of rates and/or quantities and/or schedules of works for tendering purposes and revise cost estimate, or
2B	Provide information for preparation of tender pricing documents and revision of cost estimate
3A	Prepare and make submissions under building acts and/or regulations for other statutory requirements or
3B	Prepare and give building notice under building acts and/or regulations (not applicable in Scotland)
4	Prepare further production information for construction purposes
G	**Tender documents**
1	Prepare and collate tender documents in sufficient detail to enable a tender or tenders to be obtained
2	Where applicable pass final information to Planning Supervisor for pre-tender Health and Safety Plan
3A	Prepare pre-tender costs or

3B	Provide information for preparation of pre-tender cost estimate
H	**Tender Action**
1	Contribute to appraisal and report on tenders negotiations
2	If instructed revise production information to meet adjustments in the tender sum
J	**Mobilisation**
1	Provide production information as requested for the building contract and for construction
K	**Construction to Practical Completion**
1	Make visits to the works in connection with the Architect's design
2	Provide further information reasonable required for construction
3	Review design information from contractors or specialists
4	Provide drawings showing the building and main lines of drainage and other information for the Health and Safety File
5	Give general advice on operation and maintenance of the building
L	**After Practical Completion**
1	Identify defects and make final inspections
2A	Settle Final Account or
2B	Provide information required by others for settling final account

The refurbishment projects have been divided into seven main stages in the development of a generic sustainable refurbishment project. Individual projects may depart from this model and omit some stages and include others. However, as starting point we have devised the following sequence as being of interest to planning and decision making:

Problem identification (needs, etc.). Projects begin as the result of a perceived problem, an unmet need, a technical issue or even a surplus of cash which must be spent within a specific period. The reasons for instigating a refurbishment projects are likely to be diverse and unpredictable. However, the stimulus for action can have a major influence on the execution of the project and so it will be useful to understand how these reasons relate to later stages.

Surveys–technical and social issues. Once the need for a project has been established, it is necessary to establish current conditions of the building and social conditions of the occupants. Social surveys are frequently overlooked, but in some cases they are recognised as essential to a smooth-running project.

Defining performance criteria. Ideally, the actors engaged in a refurbishment project will have a clear vision for the degree of improvement they are seeking from the refurbishment. Performance criteria will often be defined relative to current standards as required by, for example, building regulations and the current performance of the building.

Design development. This phase marks the beginning of the development of refurbishment solutions to meet the requirements identified previously. Existing models of the design process tend to underestimate the complexity of iterations that take place as designs are development and it will be difficult to capture this in the project. SUSREF has to work at a reasonably high level of abstraction, which may not represent the richness of design processes and interactions between different stakeholders.

Simulation and testing. Simulation and testing will not be part of every refurbishment project, often because the project is not sufficiently large or difficult to require specialised expertise. While this report separates this phase from design, in reality it is likely that simulation will be part of the design cycle and there will be a to and from movement between development and evaluation of potential solutions.

Construction. On paper, construction would appear to be a clearly defined and bounded of any refurbishment project. In practice, there is often on-going design activity (re-design) during this phase, which requires that the design team work with the constructors and others to arrive at workable solutions. However, in most project plans, construction is treated as a distinct stage even if the range of stakeholders is diverse.

Handover and evaluation. As with previous stages, the handover and evaluation stages are rarely as isolated and distinct as process models suggest. Construction (and even design) can continue even after the construction team has effectively left the site. Formal evaluation of projects is rare, with roughly 5% of new buildings in the UK, for example, undergoing a post-occupancy evaluation. Figures for refurbishment projects are not available, and may be slightly better given that the occupants are already in place many cases. It is important, however, to include this as an identifiable stage of the work if only to determine whether it is carried out in refurbishment cases.

8.1.3 Identifying stakeholders and their requirements, importance and influence

To identify the key stakeholders and the degree of influence and importance that they hold over the whole process of refurbishment is very important. It is also very important to understand stakeholder's relationships with each other. Their feedback will be very important input for the whole process of the refurbishment design. Therefore, it is very important to develop a list of stakeholders and their categories to provide a good coverage of all stakeholder types with their role, needs and use in the project. There are some general questions which have been asked to identify the appropriate stakeholders for any refurbishment project.

- Who is directly responsible for the key decisions on that project stage?
- Who is influential on that stage?
- Who will be affected by any decisions on that particular project stage?
- Who runs organisations with relevant interests?

- Who can obstruct a decision if not involved?
- Who has not been involved, but should have been?

Stakeholders may be existing or potential person or group who has an interest in the refurbishment project or could be the one who will be potentially affected by its outputs. They can also be end-users of the refurbishment project or those that define policies or have financial influence.

In any refurbishment project numerous stakeholders are involved directly or indirectly, all to a different extent. For analysing the whole process of refurbishment in easy and user friendly manner, it has been divided the different stakeholders into four main groups: Financial institutes, society and citizens, clients and users and construction sector. In this way, the importance and the influence of each stakeholder can be easily analysed related to various stages of project. Sustainable refurbishment of the facade are either required for the need (aesthetic, comfort, decoration etc), technical condition (energy inefficient fabric, moisture related problems, outdated facilities) or for cultural heritage. Each individual refurbishment projects has specific goals and requirements. Following are the case study from different European countries.

8.1.4 Assessment Criteria

The SUSREF project identified 15 criteria against which refurbishment projects should be judged (Häkkinen et al. 2010). These can be grouped according to the three “pillars of sustainability” that are often used to characterise sustainable development: environmental, economic and social sustainability. The criteria are shown in Figure 67.

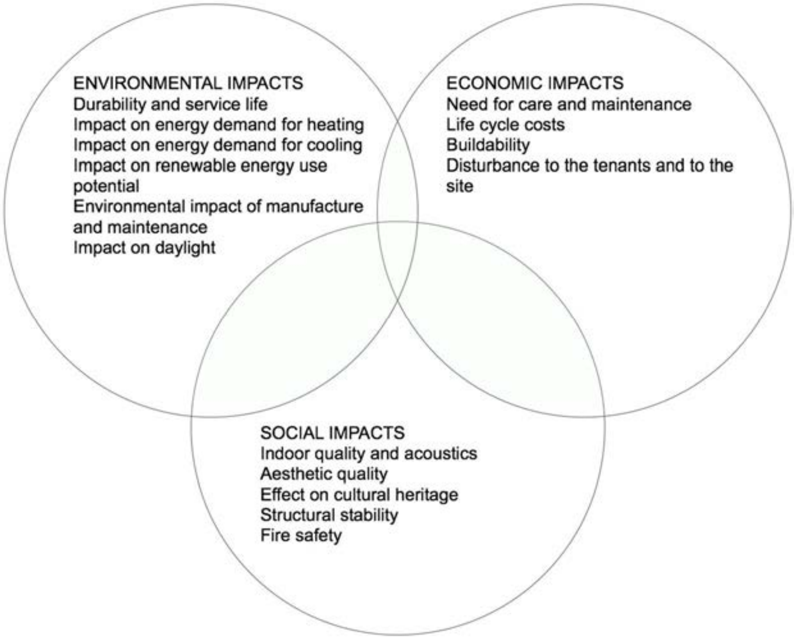


Figure 67. Assessment critieria for refurbishment grouped according to impact type (after Häkkinen et al, 2010).

The data are presented in table.

Table 77. Assessment criteria, methods and units.

Assessment criteria	Assessment method	Measured aspect	Unit
Durability and service life	Calculation/Measurement	service life	a
Impact on energy demand for heating	Calculation/Measurement	heating energy consumption	kWh/a
Impact on energy demand for cooling	Calculation/Measurement	cooling energy consumption	kWh/a
Impact on renewable energy use potential	Calculation/Measurement	renewable energy production	kWh/a
Environmental impact of manufacture and maintenance	Calculation/Measurement	carbon footprint	CO2e
Impact on daylight	Calculation/Measurement	lighting level	lux
Indoor air quality and acoustics	Calculation/Measurement	indoor environment quality (EN 15251)	good, normal, defective

Assessment criteria	Assessment method	Measured aspect	Unit
Need for care and maintenance	Calculation/Measurement	Maintenance cost	€
Life cycle costs	Calculation/Measurement	Life cycle cost	€
Structural stability	Calculation/Measurement	kN/m^2	kN/m^2
Buildability	Expert assessment	N/A	N/A
Aesthetic quality	Expert assessment	N/A	N/A
Effect on cultural heritage	Expert assessment	N/A	N/A
Fire safety	Expert assessment	N/A	N/A
Disturbance to the tenants and to the site	Expert assessment	N/A	N/A

Recommendations for the sustainable management of processes were developed with help of case studies. The studied cases were as follows:

Case Study project "Myhrerenga", Norway

Apartment complex, 7 similar blocks 3 storey high

Demonstration project "Advanced housing renovation with solar and conservation"

Case study project "PlasTirion", Wales, UK

Listed building of special historic significance, Grade II*

Three-storey house from second half of 16th Century, approximately 430 years old

Case study project TOBB, Norway

Dwellings, wooden row houses

Approximate age 30 years and the likely remaining life 30–60 years

Poor condition of windows, doors and wooden cladding

Case study project "Mustamäe 5-storey panel", Estonia

5-storey dwelling with panel-elements, built 1967

Age of the 44 years old and the likely remaining life of the building is over 50

The thermal upgrade is the part of a larger refurbishment programme

Case study project "Opetushallitus", Finland

Office house for the Finnish Board of education (Opetushallitus)

Housing area of 19 000 m^2

Approximate age of the building 35 years and likely to operate for another 100 years

Case study project ONEKA, Spain

The old Harino Panadera Industry, where the bread-flour was made

An Industrial Heritage of Vasque Country owned by the city Council.

The building was built in 1902.

Bad conditions, with some small areas of fencing demolished and almost all exterior windows broken.

Case study project "Espoon Matinkatu 14", Finland

5–9 storey residential building

The building is 40 years old and has remaining life of approximately 40 years.

The external wall renovation was the part of the larger program.

Case study project "Penrhiwceiber Terrace", Wales, UK

The building is Pre 1920 solid walled terraced property in Wales, UK.

Building has pointed random stone to southeast facing facade which is in poor condition, remaining rear facades are sand/cement render in fair condition.

The building's external appearance is protected.

8.1.5 Recommendations

8.1.5.1 Introduction

The three key points to have emerged from the case studies above are:

Diversity of processes, actors and roles. There is wide variety in the processes, actors and roles across the case studies from different countries. In the TOBB case study, for example, there is little involvement from financiers or approvers across the project stages, whereas in the "Plas Tirion" case, approvers (inspectors etc.) are involved at nearly ever stage of the project. Conversely, the user/client stakeholders are only involved at the beginning and end of the project in "Plas Tirion" but much more so in the TOBB example. In the latter case it is interesting to note that the occupants are involved as "high importance" in the defining the performance criteria.

It is also apparent that there is significant variation in the number of different actors within the broad groups used to characterise interests. For example, the "Espoon Matinkatu" case includes many different client/users.

Minimal involvement of building contractor. It is worth noting that in all cases the building contractor is usually only involved in the late stages of the refurbishment project. This is not surprising, but may have repercussions for the sustainability of the project.

The role of the architect remains central (if variable). Architects are involved most throughout the execution of these project in all countries, though their centrality varies in importance.

The cases reveal a wide variety of approaches across Europe with differences in legal framework, involvement and roles of different actors in diverse process models. This makes it difficult to arrive at a generic framework which can be applied to all projects. There is no "one size fits all" and any attempt to construct one runs the risk of becoming so abstract and high level as to be almost useless. There are, however, some key points that can be made usefully.

8.1.5.2 Framework for planning and decision making: proposals

The wall chart has been proposed for recommending the framework for planning and decision making for various stakeholders from the construction team and the design team to recommend their involvement and interaction during various design stages of the project for each performance assessment criteria. Each stakeholder team has been allocated by different colours and the intensity of the colour is darker when their involvement and interaction is of high importance at that particular project stage. The performance assessment criteria are taken from the earlier studies done on this project and are as follows

- Durability, service life and life cycle costs
- Impact on energy demand for heating and cooling
- Environmental impact of manufacture and maintainace
- Need for care and maintenance
- Build ability
- Disturbance to the tenants and to the site
- Indoor quality, acoustic and daylight
- Aesthetic quality and effect on cultural heritage
- Structural stability
- Fire safety.

The proposed framework gives the recommendation to various stakeholder groups during the suggested design stage to achieve effective interaction and involvement among themselves even for the larger projects. The comments on each performance criteria clearly explain why different stakeholders should become involved at that project stage for that particular criteria and how their involvement can be made effective. It also provide practical guidance for the way in which owners, users, corporate organization, government can interact and negotiate to address environmental, social and economic issues, the three “pillars of sustainability” that are often used to characterise sustainable development.

The proposed framework will assist practitioners to engage with other stakeholder groups, such as private sector, funders, local authorities and others. Even though this provides the guideline for all European countries, of course it will limit to the extent to which these are adopted and implemented within relevant national building regulations and guidelines.

Brief description of the suggested framework is explained by giving an example. For example, impact on energy demand for heating and cooling, the design team should keep clients and user involved during performance criteria stage to keep them aware of the solution suggested by the design team for the problem they have identified with the heating consumption at the earlier stage of the project. Also design team should interact with society on the performance criteria suggested for the project to get the funding in some cases. Another example is with the aesthetic quality and effect on cultural heritage, the problem has been identified may be by owner or Local authority. Design team get involved from the survey stage until the completion along with construction team and local authority has to look after the historic building even after completion of the project stages. Likewise all the other criterion shows the group of stakeholder involved and their influence on different project stages.

Our view is that the process would benefit from a Requirements Specification meeting early in the project so that all stakeholders are aware of the agreed needs and requirements of the occupants, funders, owners etc. from the outset. This is not unlike defining a vision for the project that will help all involved to work towards the same end points.

In accordance with our frameworks, a Sustainability Workshop should be held towards the end of the Defining Performance Criteria stage to agree targets and benchmarks. The reason for having workshop during that stage is because most of the stakeholder groups are involved and so it will be viable to agree targets with input from most of them. There is an opportunity to have another Sustainability Workshop at the beginning of Construction stage to check on the agreed targets and benchmark has been followed. Also changes to the other issues should be raised during this project stage. Further Sustainability Workshops should be arranged for later parts of the process.

Arguably the most important element we are advocating is at the end of the project. We believe it is essential for projects to be monitored once they have been handed over to the clients and occupants. This is underlined by the often ‘experimental’ nature of many refurbishment solutions, which need to be assessed in use.

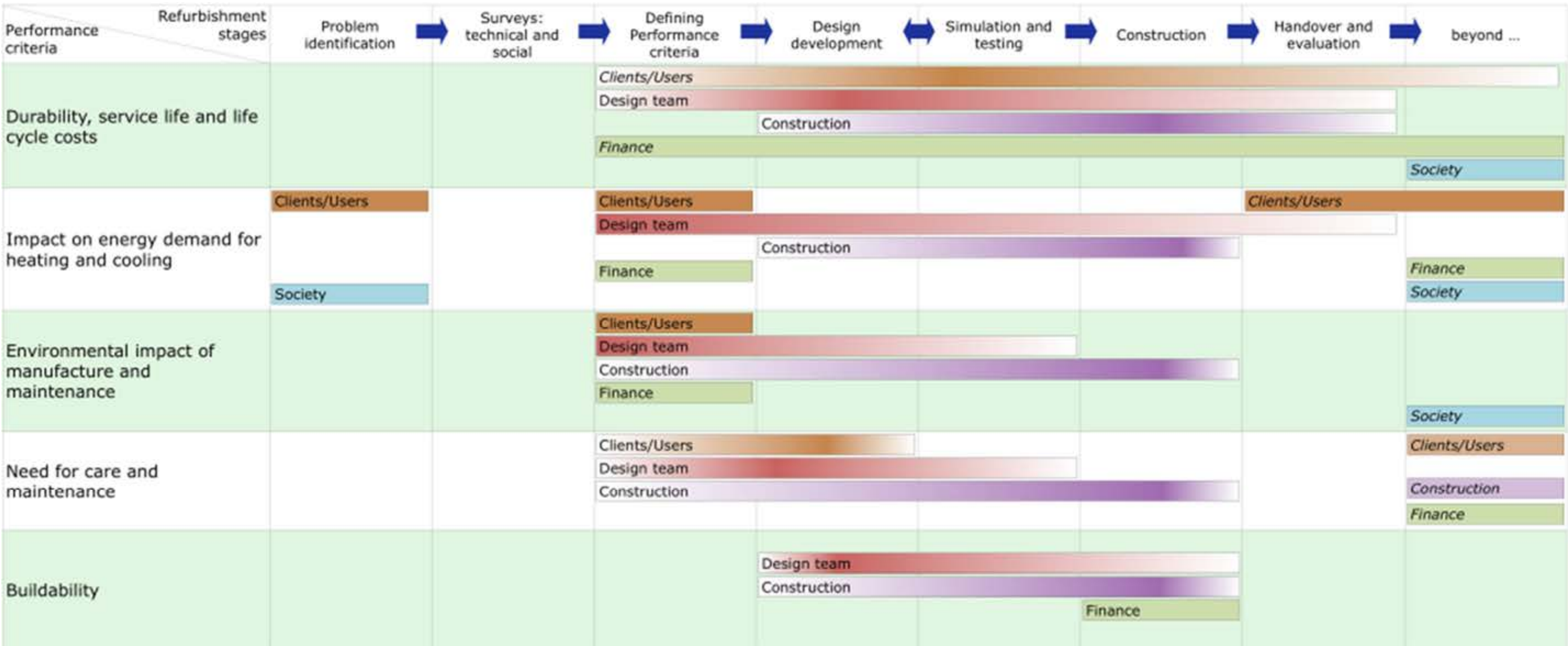


Figure 68. Framework for planning and decision making.

NOTES OF THE PROCESS CHART

Durability, service life and life cycle costs

During the process of designing, planning and constructing the building, the actors involved in the design process need to match the energy performance expected by the design solution with the performance requirements for durability, service life and life cycle costs. The manufacturer and the supplier of the products for the refurbishment may have to check the performance criteria against recognised norms before proposing a product to the design team for the assessment of design options. A design option is considered reasonable when it meets the performance requirements over the period set for the specific projects. Finance actors should be involved from the *Defining Performance Criteria* stage to check on the cost of the product used for the refurbishment.

Impact on energy demand for heating and cooling

In most of the case studies, the clients and users have identified the problem as the heating consumption. The design team is involved in the various project stages to assess the impact on energy demand. Construction actors should be involved in *Design Development* stage along with the design team. Finance actors provide funds for the refurbishment on the basis of the performance criteria and at some point they need to compromise between heating energy consumption and costs of refurbishment. As for Finance, the local authority gives approval to the building work on the basis of reduction in energy demand for heating if this is possible at reasonable cost to client.

Environmental impact of manufacture and maintenance

From *Defining Performance Criteria* stage, the Construction team along with the design team will start considering the life cycle and carbon footprint of the material used for the refurbishment and its environmental impact. The life cycle of the material covers all the phases of material life from the extraction of the natural resources, transportation to the site, design, manufacture, assembly, use, maintenance and repair. By end of the Testing stage they will decide on the material by balancing the environmental impact of the material with all its life cycle phases and the energy saving achieved by using that material. Society will be involved beyond the handover and evaluation stage to look after the life cycle of the materials used for the refurbishment.

Need for care and maintenance

During design development stage the care and maintenance of the building should also be considered because wrong decisions often leads to an installation that is more costly to maintain than necessary. Once the building is completed, the owners will be responsible for the costs throughout the life of the installation. Therefore, from Defining performance criteria stage till Testing, the design team will be involved in selecting the installation which will incur lower care and maintenance cost over its life for the owner. Clients and users are also involved at the beginning of this phase of the project and than reappear faintly after completion of the project.

Buildability

Buildability is of high importance at the construction stage of these case study projects because it allows the construction team to propose the method of construction which provides benefits and solutions to achieve a suitable design in a cost effective and timely manner. The design team works along with Construction to incorporate the solutions.

Disturbance to tenants and to the site

Disturbance to the tenant and to the site have to be minimised and these criteria need to be included from the beginning of the Defining performance criteria stage. Available working space and accessibility need to be considered while deciding on the refurbishment option. Contractor evaluates a project on how possible it will be to minimize disruption and nuisance to the environment. Society (neighbours; inspecting and enforcing authority) may have a role during the construction stage.

Indoor air quality, acoustics and daylight

Occupants and owners have identified the problems with poor air quality and acoustics in the building. The design and construction teams need to consider the effect of alternative refurbishment concepts on the reduction of risk for moisture related problems like corrosion and mould growth and poor air quality. These are assessed with help of building physical simulations. The acoustic quality is assessed in terms of air sound insulation factor.

Note: this research project does not include sound insulation testing.

Aesthetic quality and effect on cultural heritage

With a building of historic importance, the aesthetic quality and its effect on cultural heritage is significant. The design team establishes compromise between conserving historic fabric & character and upgrading for energy efficiency in non-damaging & reversible manner. The design team checks to make sure no proposals make standards worse or have adverse effects on historic buildings. The design team also tries to preserve traditional building techniques. A decision is agreed with the local authority on technical limits within aesthetic and conservation restrictions. This local authority regulates work on this type of building and will be involved with design team through all the stages of project to protect the historic character of the building.

Structural stability

Structural survey needs to be done by the Construction team or the design team before altering any load bearing part of a structure. The structural survey should consider the age of the structure, type of construction and any nearby buildings or structures. The design team should consult the building control department of the local authority in the area where building is located before any structural alterations are made to the building. The design team along with Construction team work on the structural stability criteria at technical survey stage of the project.

Fire safety

In UK, the Building Regulations part B, Volume 1 deals with Fire Safety for domestic buildings. Other European countries have different approved documents for fire safely. These documents provide the rules from the basic installation of smoke detection in a domestic property to full fire safety protection. The design team works with the local authority building regulation officer at the design stage of the project to decide on fire safety requirements because it can be very expensive to add requirements in later stages. The construction team also gets involved with this aspect during construction as the correct installation of components is essential.

Recommended actions and events

In our analysis of the case studies and literature it has become clear that ensuring good communication and understanding between actors lies at the heart of good practice in refurbishment (and other projects). The suggestions indicated to the left are intended to serve as a reminder to communicate needs, intentions and plans to actors engaged in the various refurbishment processes. While the need to attend meetings is often resisted by many because of the time commitment, it is our view that a little more time spent together will reduce the time required to fix potential problems later in the process.

8.2 Guidelines for building industry

8.2.1 Introduction

The main aim of SUSREF project has been to develop product concepts for a sustainable refurbishment of external walls. This Chapter summarises the results and gives guidelines for building industry. The purpose of the guidelines is to support the development of sustainable concepts for the refurbishment of exterior walls.

The following sections include summaries and conclusions of several analyses presented in earlier reports. Only the main results are given here, the background analysis may be found from the source technical reports. The topics included here are related to durability, fire safety, structural issues, energy and life cycle performance. The results drafted from these topic areas are given as recommendations for the industry to be applied in refurbishment projects.

8.2.2 Construction process

The construction process of a refurbishment project differs from that of a new building project. There usually are preconditions and limitations that are fixed in a refurbishment project. These may affect the working methods, material choices, work timing etc. of the project. Such limitations might be:

- Space available around the building for waste materials and new materials storage
- Logistics of the work process
- Building use during the refurbishment
- Availability of materials and human expertise.

A refurbishment project should develop at least the following plans or decisions prior to the initiation of the site work:

- Client requirements of the refurbishment are established
- Structural plans of the different work stages
- Descriptions of the works stages and material logistics on the site
- Scaffolding and weather protection methods applied
- Technical assessment of the walls to be refurbished and compatibility of the results with the refurbishment methods chosen
- Information delivery plan to be handed to the building users/clients and other interest groups during the work execution
- If prefabrication is applied, tolerances on the dimensions should be set.

8.2.3 Technical guideline

DURABILITY

<u>Introduction</u>

The building materials, connections and detailing of the building envelope must withstand several types of loads either related to climate factors or mechanical actions.

Figure 69 shows the typical deterioration mechanisms that cause building materials and components to fail over time. The strength properties are the easiest and most accurate to design and predict. Moisture flow through a wall is also possible to predict. Moisture significantly affects the durability performance of building materials. Most of the deterioration mechanisms are however impossible to predict very accurately, additionally, the material performance may be highly variable. These are for instance degradation of polymers, salt migration etc. These life shortening phenomena can be avoided or at least reduced radically by selecting suitable building materials and by structural detailing. Models to calculation the durability of concrete in exterior climates do exist, with regard to frost damage, carbonation and corrosion of reinforcement. Models for mould growth also are known. These are presented in the following sections.

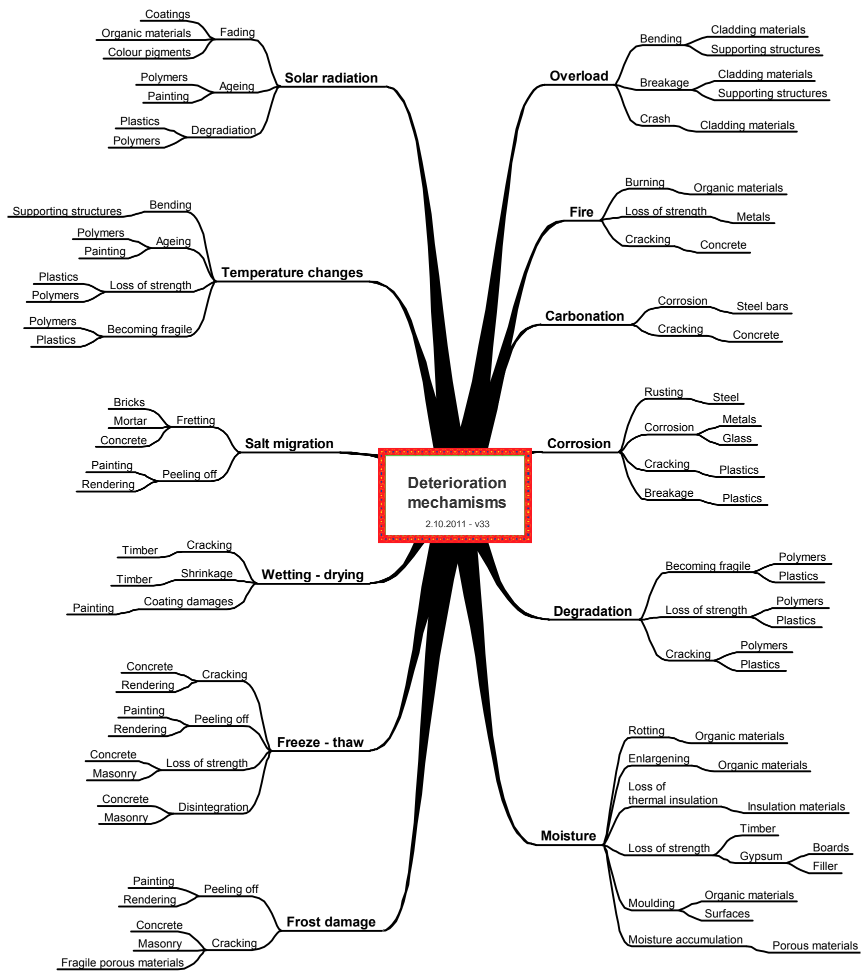


Figure 69. Deterioration mechanisms of the building envelope.

<u>Moisture performance of refurbished exterior walls</u>

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 a wall. A water vapour barrier may be needed near the inner surface of the wall.

Sources of moisture in the wall are driving rain water leakages through connections or construction faults, unprotected construction works or internal condensation. This is harmful if the wall has limited drying potential and there does not exist a ventilation gap behind the facade. 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 very risky. Excessive moisture levels may cause mould. This may be a risk considering also the indoor air quality.

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. The existing wall will become warmer and dryer. There is no critical theoretical limit of thermal insulation thickness, the thicker the better usually. If the new outer layer is water vapour tight, a ventilation air gap between retrofit insulation and the new outer layer is needed to remove moisture from the structure. The old outer layer and possibly the old thermal insulation may need to be replaced with new ones. The same principles mentioned above apply also in these cases. It should be emphasised, that there is always a mould growth risk, if existing structures are covered by vapour tight layers (as PUR) and there are leakages in the outer layers or the existing wall is originally high in moisture content.

When adding retrofit insulation in the wall cavity, care must be taken that there will not be any empty spaces left. 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 these pose less risks of breakage. The bindings in between an inner and outer layer reduce the effectiveness of the added thermal insulation.

When adding retrofit insulation on the 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 the 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 effective on inner surface of a wall as on outer surface, because on inner surface there are cold bridges, which cannot be insulated.

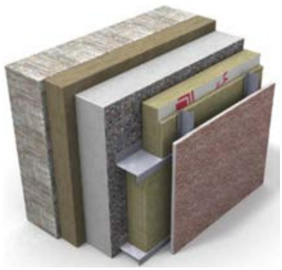
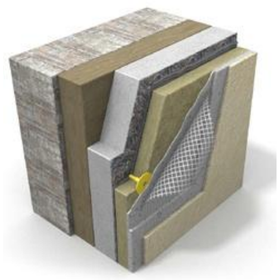
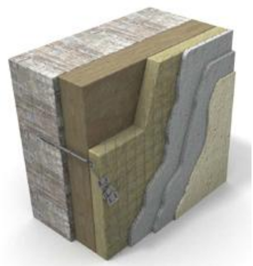
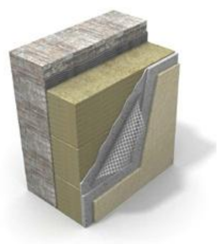
How to ensure that the refurbished wall will be durable for as long as possible? Here are some principals that are recommended to direct the design:

- ensure that the walls and their joints are airtight and the water vapour permeability of the 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 in this case 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 by experience
- ensure, that the old wall can hold the extra weight of the retrofit part and if not, add extra bindings and fixings to the old wall
- design the structure and it's joints, sealing 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 detailing between window, wall and external window sill
- control the quality of manufacturing and installation
- make inspections periodically to the building site
- repair found defects in time.

Tables 78 – 80 show refurbishment methods of different wall types together with possible problems which may occur. The tables are schematic examples and the real wall structures should be checked in each case with the actual material properties and thicknesses with the climate data of the building location. If a one-dimensional simulation shows 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 the refurbishment. There are uncertainties involved here, such as material properties used in simulations and bad workmanship creating for example holes in water vapour barriers, air leakages, water leakages and the performance of air gaps between material layers.

Table 78. 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),
(problems related to frost apply naturally to climate conditions where frost occurs).

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

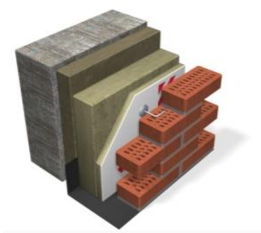
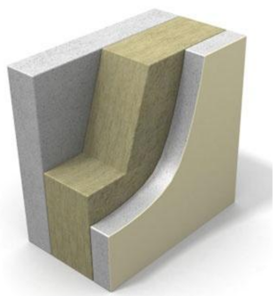
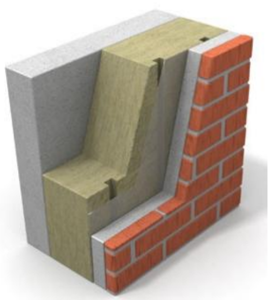
Refurbished wall	Description	Possible problems	Check following
	- Outer layer removed - Extra insulation on old insulation - wind shield mineral wool - ventilated air gap - brick wall	- rain water penetration behind brick wall - frost damages of bricks - moisture condensation behind brick wall	- frost resistance of bricks - ventilation of air gap - support of brick wall - rain water penetration through brick wall

Table 79. 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

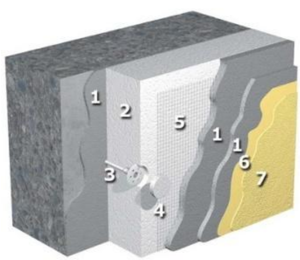
Refurbished wall	Description	Possible problems	Check following
	- mineral wool insulation on old exterior surface - render with float and set	- rain water penetration through mortar - frost damages of mortar - condensed water vapour accumulation in mortar layer	- water vapour permeability of materials - 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

Table 80. Refurbishment method of timber frame walls and their moisture risks. (Photos from Paroc Oy).

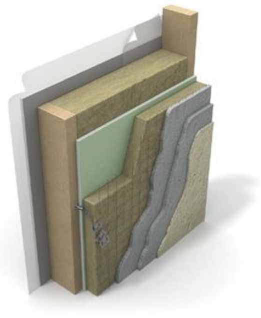
Refurbished wall	Description	Possible problems	Check following
	- Outer layer possibly removed - mineral wool insulation on outer surface - render with float and set	- rain water and inside air moisture penetration behind surface layer - frost damages of concrete layer	- water tightness of joints - water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

Table 81. Different refurbishment methods on inner surface of walls and their moisture risks.

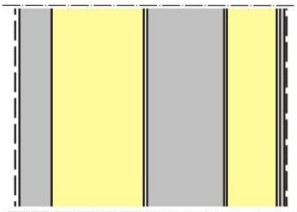
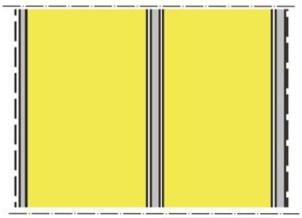
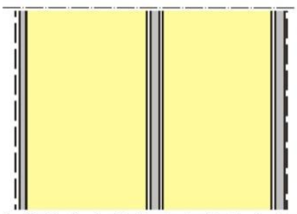
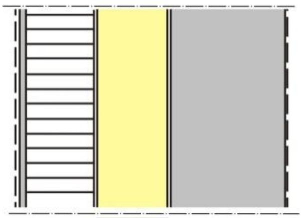
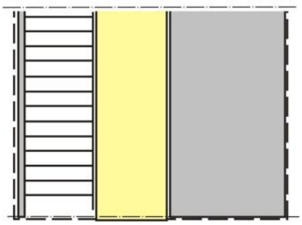
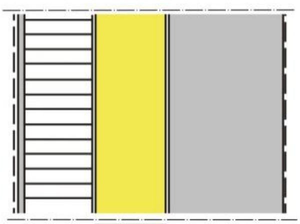
Refurbished wall	Description	Possible problems	Check following
	- EPS or PUR foam on inner surface of a wall - gypsum board	- partition walls and floors are thermal bridges and they reduce the effectiveness of retrofit insulation - condensation on inner surface of old wall	- contact between thermal insulation 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

Table 82. 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

<u>Deterioration of refurbished concrete facades</u>

In this chapter estimations based on computer models have been carried out to study possible risks in the long term performance of refurbished concrete sandwich walls. The different refurbishment concepts were exposed to European climates. The calculations were carried out 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 carried out as separate case studies. The original (before refurbishment) sandwich wall was kept the same, however with two alternatives for 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 these both alternatives were considered.

The simulated degradation types were frost attack, carbonation, 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.

Refurbishment Concept E1[39] – additional insulation laid on the original outer core of the sandwich and covered by a layer of rendering

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 vapour tight layers. The moisture which was left to the original concrete core cannot dry out in a reasonable time. That is why there is a high 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 may 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 interior. 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 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 °C. The risk of frost attack is increased when the rendering is let to be exposed to driven rain and freezing immediately after manufacture – without a sufficient hardening period.

Refurbishment Concept E2 – mounting insulation boards on top of the original sandwich and covering it with masonry panel boards, a ventilation gap between the panel and the thermal insulation

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

39 E referes to external insulation

occurring 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 insulations. 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 the long term, this 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 framework of the board. The framework of the panel boards is usually made of a zinc coated steel plate which has a limited service life.

Refurbishment Concept R[40] – original outer concrete core and the original thermal insulation removed and replaced by a new thermal insulation and a layer of rendering on top the insulation board

In Refurbishment Concept R the original outer concrete core and the original thermal insulation are removed and replaced with a new thermal insulation layer and a layer of rendering on top the insulation 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.

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 materials, such as ESP and PUR. Concept R seems to be relatively risk free. However, in cold weather climates 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.

8.2.4 Fire safety

Assessment criteria

To achieve sufficient safety for people in or around the building, to reduce the damage on material properties, and to reduce the impact on the environment and society, buildings must be planned and built with sufficient fire safety. This can be accomplished by using materials and products without unacceptable contribution to the ignition and development of the fire, and by designing the building, building

40 R refers to replacing renovation

parts and installations to reduce the development and spread of fire. In addition to reducing spread of fire between the compartments in a building, the design shall also limit the risk of fire spread between buildings. The design must also facilitate quick and safe evacuation from the fire. And it must reduce the risk of a premature structural collapse, which can obstruct safe evacuation and rescue of the people in the building and lower the possibility to restore the building after the fire. When refurbishing a load bearing or non-load bearing façade the fire safety might be affected, and this must therefore be evaluated. The fire safety of the refurbishment concepts is in this project assessed based on their *reaction to fire* and their *fire resistance*. The reaction to fire is the material's ignitability, rate of heat release, rate of spread of flame, rate of smoke production, flaming droplets/particles and/or a combination of these safety aspects. The fire resistance is the load bearing structure's or the fire separation wall's ability to maintain its load bearing, insulation or integrity properties when exposed to a fire. The effect of the refurbishment on the reaction to fire and fire resistance is assigned to a qualitative scale according to the criteria given in Table 83.

There are mainly two scenarios for a fire; the wall can be ignited from the internal side or the external side. A fire that starts inside the building can become very severe and the temperatures and pressure can result in the breaking of windows, or burn through of internal separating walls and ceilings. If the fire starts on the external side of the wall or spreads from the inside to the outside through windows, the flames can spread on the facade to other units of the building.

<u>Reaction to fire</u>

The evaluation criteria are as follows:

- Contribution to fire: Reaction to fire classification of components and the whole system
- Combustible products protected – yes or no
- Cavities present – yes or no
- Combustible surfaces in cavities – yes or no
- Fire stops in cavities – yes or no
- Falling of particles (includes fire performance of fixing mechanisms)
- Number of stories (when combustible products used).

<u>Fire resistance</u>

The evaluation criteria are as follows:

- Load bearing structures: R (15, 30, 45, 60, etc. min)
- Fire separation walls: E (integrity) and I (insulation) (15, 30, 45, 60, etc. min).

<u>Qualitative scale for assessment</u>

The effect of the refurbishment on the reaction to fire performance and the fire resistance of the wall and façade are assigned to a qualitative scale according to the criteria given in Table 83.

Table 83. Qualitative scale for assessment of refurbishment effect on reaction to fire and fire resistance.

Score	General effect of refurbishment	Effect of refurbishment on Fire safety
-2	Significant aggravation	Significantly increased risk of ignition and spread of fire, or significantly reduced fire resistance
-1	Minor aggravation	Slightly increased risk of ignition and spread of fire, or slightly reduced fire resistance
0	No change	No effect on ignition and spread of fire, or fire resistance
1	Minor improvement	Slightly reduced risk of ignition and spread of fire, or slightly improved fire resistance
2	Significant improvement	Significantly reduced risk of ignition and spread of fire, and significantly improved fire resistance

Sometimes an increased or reduced risk of ignition and spread of fire, or fire resistance due to the refurbishment is insignificant to the necessary total fire safety of the building. For a small house (single family) ignition is the only important factor, while for a multi-storey building with several units all three factors (ignition, fire spread and fire resistance) are all very important.

Assessment results of Cases E, I, C and R on fire safety

An example of assessment of the external insulation (E) refurbishment concept on the fire safety of the different wall types is given in Table 84.

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Table 84. Assessments of the refurbishment External insulation's effect on the fire safety of the external wall and facade.

External insulation (E) – New outer service with retrofit insulation **– effect on Fire Safety**					
A = Small houses B = Terraced houses C = Multi storey	External structures/layers: Thin non-combustible = Metal, rendering, etc. Combustible = Wood, PVC, etc.		Non-combustible insulation = Mineral wool Combustible insulation = EPS/XPS, PUR/PIR, cellulose based, etc.	E1 = Insulation fixed without air gap E2 = Insulation fixed with air gap and wind protection	
WALL TYPE	**BUILDING TYPE**	Type of external structure/layer	Type of insulation	**Score**	
				E1	E2
W1_Solid wall; Brick, natural stone	**A**	Brick, natural stone or similar	Non-combustible	0	0
			Combustible	0	-1
		Thin non-combustible	Non-combustible	0	0
			Combustible	-1	-2
		Combustible	Non-combustible	-1	-1
			Combustible	-2	-2
W2_Sandwich element; concrete panel + concrete panel	**C**	Concrete or similar	Non-combustible	0	0
			Combustible	0	-1
		Thin non-combustible	Non-combustible	0	0
			Combustible	-1	-2
		Combustible	Non-combustible	-1	-2
			Combustible	-2	-2
W4_ Load bearing cavity without insulation; brick + concrete block W5_Insulated load bearing cavity; concrete block + concrete block W6_Non-load bearing cavity; hollow brick + perforated brick W7_Non-load bearing concrete block without insulation; hollow brick + concrete block	**A**	Brick, natural stone or similar	Non-combustible	0	0
			Combustible	0	0-1
		Thin non-combustible	Non-combustible	0	0
			Combustible	-1	-2
		Combustible	Non-combustible	-1	-1
			Combustible	-2	-2
	B	Brick, natural stone or similar	Non-combustible	0	0
			Combustible	0	-1
		Thin non-combustible	Non-combustible	0	0
			Combustible	-1	-1
		Combustible	Non-combustible	-1	-1
			Combustible	-2	-2
	C*	Concrete or similar	Non-combustible	0	0
			Combustible	0	-1
		Thin non-combustible	Non-combustible	0	0
			Combustible	-1	-2
		Combustible	Non-combustible	-1	-2
			Combustible	-2	-2

*Not applicable for wall types W6 and W7

To ensure the intended fire safety level when applying new external insulation (E) 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. Ventilation cavities between the insulation and external boards are recommended to be avoided.

The most common solution when refurbishing the wall by applying internal insulation (I) is to leave the existing internal separating functions untouched. The insulation is added to the inside of the external wall, and therefore, the refurbishment may affect the risk of ignition, fire spread and total fire load. Thus addition of combustible insulation and/or inner linings should be limited or combustible insulation should be properly protected according to fire safety requirements of concern.

In cavity insulation (C) cases the insulation (which may be combustible) is protected from direct fire exposure by brick or concrete wall. Making penetrations or installations after filling the cavity may cause a fire hazard because combustible insulation may ignite from hot tools used for instance. After refurbishment there are no air cavities enabling the spread of fire.

In the replacing renovation (R) concept, combustible cladding might cause spread of the fire to the floors above, and combustible insulation might cause fire to spread inside the wall to the next storey. 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. Ventilation cavities between the insulation and external boards are recommended to be avoided.

8.2.5 Structural issues

Structural stability

The term structural stability is the condition of the existing wall regarding to the structural performance of the building. Assessment of structural stability is restricted to a qualitative assessment of how the following properties will be affected by the refurbishment:

1. Structural performance of the wall and the building (load bearing capacity)
2. Mounting of fastening points in the existing wall
3. Changes in water drainage, changes in humidity and danger of frost heave
4. Sensitivity for seismic loads.

Normally the structural performance of the wall and the building will remain unchanged. The insulation materials weights are low and the additional load from the refurbishment is also normally low. The assessment of the load bearing capacity of the existing walls must also include a verification to ensure that it can withstand the mounting of fastening points. The wind load will not increase due to refurbishment. Changes in water drainage, changes in humidity and danger of frost heave etc. may affect the structural stability in the long term.

8.2.6 Buildability

Assessment of buildability is restricted to the following properties and related tasks during the refurbishment action: current condition of the existing wall, constructional feasibility, access to the building site, domestic factors and climate.

The quality of the existing wall must be assessed. Assessment of current conditions of an existing wall will show the need for repairs and suitability of the refurbishing method prior to refurbishment. Necessary repairs might be removal of cladding or improving drainage. Furthermore it is imperative to assess the load bearing capacity of the existing wall. A visual assessment of a cladded wall will not necessarily reveal possible moisture damage beneath and therefore it is not enough.

Well established building methods facilitate the work not requiring highly qualified craftsmen of special skills. Level of prefabrication is directly influencing the need for specialized craftsmen. For vacuum panels, prefab is the only solution. Prefab is quick and easy to mount/assemble and seldom demands special tools, whilst in-situ solutions are adaptable but require tools and skills. Prefab gives an advantage when the wall consists of large areas of smooth surface.

The following insulation materials are in common use:

- Cellplastic foam
- Glass wool
- Rock wool
- EPS/XPS
- Vacuum panels.

The thermal insulation properties of these insulation materials vary, but in the context of buildability, the workability is more of concern. Cellplastic, glass wool and rock wool can easily be cut and reformed, as also eps/xps, while vacuum panel cannot be cut at the building site.

Is there enough room around the building to refurbish using the concepts? Is it possible to build scaffolding around the building? Internal insulation (type I) and Cavity insulation (C) might be the only possibilities without scaffolding. Any kind of exterior refurbishing requires scaffolding, even for small houses. Some refurbishment systems are more sensitive to rain, hence a tarpaulin is often needed.

To ensure choosing the proper refurbishment method, it is important to take into account the existing local building cultures, relying on indigenous expertise and experience. These are matters crucial for all achieving the right combinations of wall type and refurbishment methods, in order to optimize the outcome.

There might be cultural and conservation measures constricting the possibilities for refurbishment. This causes a distinction between interior and exterior insulation. Furthermore, the purview differs within European countries, restricting the refurbishment alternatives or the thickness.

Dependency of weather conditions and climate zones must be assessed. It is imperative to render special attention to climate zones where the temperature fluctuates frequently about the zero point due to condensation issues. This is especially important when using refurbishment method ”I” (internal). There might be a need for developing the climate distinctions further. In some areas there is often hard, driving rain, which creates problems both during the construction period and through the life span of the building. A wall in the coastal regions of Norway for instance will be exposed to hard, slashing rain and frequent fluctuations around the zero point in temperature, creating condensation.

8.2.7 Energy and life cycle performance

Impact on energy demand for heating

The placement of the insulation has a different influence on the heating energy use even if the thermal conductance (U-value) of the walls were the same. This results from fact that the extra insulation changes the active thermal capacity of the wall. The thermal capacity of the wall determines the property of the wall to store heat. In general, internal insulation decreases the active thermal capacity with regard to varying internal heat loads like heat from home equipment, heat from people and solar heat that comes to the room through windows. This decreased heat storage capacity reduce the utilization of internal heat loads in heating especially during spring and autumn when the heat loads are big compared to the heat demand. Whereas cavity and external insulation increases internal active heat storage capacity of the wall thus enabling the utilization of the internal heat loads and reducing the heating energy use. The effect of the placement of the insulation on the heating demand can only 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 used here.

The results reveal that the biggest saving potential is in single family houses which arise from the fact that in the single family house the wall area compared to the floor area is larger than in the other building types.

The climate has a significant influence on the saving potential as for instance the heating energy saving potential is substantially bigger in England than in Spain due to the differences in climate and refurbished cases used in selected examples. In all cases however, the heating energy saving potential is substantial.

It should be reminded that heating degree day analysis gives usually the maximum saving potential that can be achieved with conventional extra insulation refurbishment. In practice the savings are in most cases lower because the extra insulation affects the utilization of internal heat loads (sun, appliances, people) that cannot be taken into account with this method.

There are also practical details that define the success of the extra insulation. Only with external insulation it is possible to cover the whole shell of the building.

In wall cavities there are usually bonds between the external and internal walls that form thermal bridges in cavity insulation thus weakening the heat resistance of the wall. Moreover the insulation work of the cavities is technically difficult to carry out so that all the cavities are really insulated according to the specifications. Internal insulation is practically impossible to install without breaks in the insulation because of the internal walls and ceilings which decreases the effect of the thermal insulation. The internal and cavity insulation are also sensitive to errors in design and in installation in regard to condensation problems.

Impact on energy demand for cooling

The calculations show that façade insulation reduces 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.

Nevertheless, this method does not take into account that walls also increase the thermal capacity of the building, and thus, internal insulation can lead to a reduction of the effective thermal capacity of the building. Care should be taken in this case, as this can result into higher peak cooling loads in Mediterranean climates. These cases can only be properly addressed by direct dynamic modelling and simulation of the whole building.

8.2.8 Life Cycle Costs

The Life Cycle costing covers here only the extra building costs and energy cost caused by the refurbishment compared with necessary refurbishment of facades. The analysis basis includes price of money (+ 2%/y). Economic assessment is based on the calculation of life cycle cost according to ISO 15686-5 Life Cycle Costing (LCC)[41]. LCC is a technique for estimating the cost of whole buildings, systems and/or building components and materials, and used for monitoring throughout the lifecycle.

These refurbishment concepts have been compared to a basic case in order to observe the difference 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 does not need repair itself. If the energy price increasing rate is high, the refurbishment may become more profitable.

When comparing different options, the effect of the decrease of housing area (5% in average) in the case of inner insulation, has to be taken into account additionally.

The costs of separate refurbishment actions vary a lot in Europe. Especially the cost of additional insulation is often non economical. However, the energy saving

41 ISO 15686-5 Life Cycle Costing.

potential may be very high with a short payback time at least in the cases where an adequate investment support is available.

The economic impacts of the refurbishment concepts can be summarised as follows:

- significant reduction of energy consumptions and carbon footprint
- reasonable increase of investment cost
- relevant savings in life cycle cost
- increase of resale value.

The most remarkable risks concern

- management of changes in energy production
- adequacy and management of movements of labour connected to timing, quality and cost demands
- management of damage mechanisms of façade structures
- possible cost and health effects of individual unsuccessful refurbishments.

Most remarkable possibilities are

- acceleration of refurbishment innovations
- adequate training programmes of companies and labour
- new kind of financing and supporting mechanisms
- creating concepts where thorough renovations are carried out in the context of big areal refurbishment projects.

However, the more promising increase of economic value (market value) can be achieved with the help of refurbishment 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 the help of the increase of market value. This can also be realised by increasing the density of the area. The increased use of sustainable building classification methods may also increase the value of refurbished areas.

8.2.9 The environmental impact of building renovations

The magnitude of environmental impact in building renovations depends on the existing building type, building condition and renovation concept used. In traditional building design, where buildings are of square and rectangular shape, the exterior wall forms 1.2–1.5 wall-m^2/one floor-m^2, but the ratio depends on the structure used. Wall structures with relation to the material weight (amount) could be divided into light, medium and massive structures and when the amount of used material is high normally also the environmental impact is also higher in comparison to lightweight cases. The same principle is applicable also for renovation concepts, the lighter the structure used, the smaller 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 efficiency, 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 renovation concepts could be applied to the existing wall externally, internally or to the wall cavities. This study focused mainly on the external and internal renovation cases because the material consumption into the wall cavities remains small and doesn't give such a big effect in the sense of energy savings and environmental impact. Nevertheless cavity walls are included when the renovation is applied internally or externally. The examples are given for chosen building types to illustrate the ability of energy saving building renovation and the environmental impact.

Main findings in this study related to the insulation thickness, insulation type, façade type and energy type used are:

- Energy efficiency from specific insulation types depends on their thermal conductance. Insulation materials could cause a large range of variation in thermal conductance, 0.07–0.44 W/m^2K and accordingly a 100 mm insulation could cause annually heat transmission in North Europe 8–50 $kWh/m^2/y$. In the same time insulation materials have also different specific weights which mean that the amount needed in wall renovation to achieve the same efficiency differ. On the other hand insulation materials are developed for certain conditions and with certain properties which makes the selection of right materials into the concepts highly important. Insulation material selection has high impact not only to the energy and physical performance but also to the environmental impact assessment result.
- Expanded polystyrene, polyurethane, rock wool and lamb wool are studied which all have the same thermal resistance but a different material consumption to achieve the same U-value. According to the result, PUR and EPS, which are fossil based materials, caused highest environmental impact whereas the lowest impact was achieved with the use of by product materials. In this study lamb wool was considered as a by-product material and no production impacts were allocated for the waste. Lamb wool could be considered as a waste product because some wool types have properties which are not suited for the textile industry and these are exploited only for the meat industry.
- The optimal consumption of insulation materials depend on the building condition and the geographical region. As an example, in Northern Europe a 300 mm rock wool saves a reasonable amount of energy and reduces carbon emissions but in Southern Europe the optimal amount remains less than 100 mm.
- In the external renovation case where the façade is installed with a ventilation gap makes it possible to use various façade materials. Façade types studied in this survey were concrete, wood and clay brick façades.

    - Best façade material which causes least environmental impacts, carbon footprint, non-renewable raw material and energy consumption, was the wooden façade. This renovation concept is the light weight option, wood is a renewable raw material and timber production utilizes production wastes for energy which also is a renewable source.
    - In the case of a U-value of 0.28 W/m^2K the material share of the carbon emissions for Nordic regions is 4–20%, but in the case of a better insulation (U-value 0.12 W/m^2K) it is 30–40%. In Central Europe the material share in carbon footprint for better insulation is 38–52% and in Southern Europe it is 58–70%.
- A replacement renovation concept enables to keep or change façade features. In the concrete element renovation case with the concept of an outer concrete layer replacement, the amount of new added concrete is high. The material consumption causes higher carbon footprint compared to the case of a 3 layer rendering façade, where the material amount is lower.

  The replacement concept with concrete and insulation having carbon footprint value 50 kg/wall m^2 is twice as high as the lighter weight renovation option, rock wool with a 3 layer rendering façade.
- The material share of the total carbon footprint depends on the heating energy consumption and heating type.
    - In the regions where the heating period is long, Northern Europe, the materials used in wall renovation could cause up to 41% of the total carbon footprint (renovation materials and heating energy for a 20 year operation). This examination performed to the renovation case where renovation solution mineral wool with 3-layer rendering façade and heating energy was produced with the Nordel electricity mix (where the renewable energy amount is high).
    - For the U-value 0.21 W/m^2K material share between different heating types varies between 10–15%, but in the case of U-value 0.1 it is varies between 30–41%. The material share could be higher, when higher amount of heating energy is produced from renewable resources.
    - The material share is much higher in southern Europe where the heating energy consumption is lower.

The study has shown that the exterior wall renovation can achieve a significant reduction in energy savings and environmental impacts. Which renovation option is suitable and best in each particular case should be determined according to the overall building condition, historical background and building region. Walls are only part of the buildings and differences in the building level should be examined more comprehensively afterwards.

8.2.10 Recommendations

This report draws 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.

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 the indoor air quality.

Considering 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.

Considering 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.

Considering 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.

Considering 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.

8.3 Recommendations for standardisation bodies

8.3.1 Introduction

In order to ensure the strong impact and dissemination of the SUSREF project outcomes, the results summarise relevant standards for sustainable renovations which might need revision and recommendations for standardisation bodies.

The result is important with regards to following regulation and standardisation works:

- European Construction Product Regulation
- Energy performance in Buildings Directive
- environmental assessment of building products and buildings
- environmental product declarations
- service life assessment.

According to CEN definition a standard is a technical document designed to be used as a rule, guideline or definition. It is a consensus-built, repeatable way of doing something. The standardization is the process of establishing a technical standard, which could be a standard specification, standard test method, standard definition, standard procedure (or practice), etc.

Standards can be de jure, de facto or voluntary standards. De jure standards are the standards which are part of legal contracts, laws or regulations. De facto standards are in dominant usage and followed by informal convention. Voluntary standards are standards which are published and available for people to consider for use.

SUSREF project have developed sustainable concepts and technologies for the refurbishment of building facades and external walls. To ensure the sustainability of developed technologies the project has outlined a framework according to which the sustainability of alternative concepts should be assessed. The framework includes 15 aspects, which are as follows: durability, need for care and maintenance, indoor air quality and acoustics, impact on energy demand for heating, impact on energy demand for cooling, impact on renewable energy use potential (use of solar panels etc.), environmental impact, life cycle costs, aesthetic quality, effect on cultural heritage, structural stability, fire safety, buildability, disturbance to the tenants and to the site, impact on daylight. These issues have been handled also in standardization work made by ISO and CEN, but not clearly indicated for the use of refurbishment assessment. This Section outlines fields were exisaiting standards may need revision, or new standards are desirable to facilitate sustainable refurbishment.

8.3.2 Relevant standards which might need revision

<u>ISO and CEN standards about environmental aspects</u>

ISO and CEN have developed standards for sustainability assessment in building construction. This work is done by European technical committee TC 350 (CEN), Sustainability in construction works, and international technical committee TC 59 SC 17 (ISO), Sustainability in building and construction. Section 3.1.1 explains the structures of the current standardisation work.

Product level standards

ISO 21930:2007 standard provides the principles, requirements and specifications for environmental declarations (EPD) of building products. This standard listed the group of life cycle stages and gives mandatory, optional elements and information modules in declared and functional unit. When the declaration includes only certain life cycle stages the declaration becomes a module of information and EPD expressed per declared unit (for example cradle to gate). But when the declaration includes all life cycle stages, the declaration said to be “cradle to grave”, it becomes an LCA for a building product.

CEN Technical Committee TC 350 worked out product level environmental declaration standards which contains product category rules (PCR), communication format from business to business use and methodology for 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.

We recommend clarifying the terms functional unit and building performance, when these standards are applied for products and com-

ponents which are meant for building refurbishment and renovation use. Principally these standards are applicable for all building materials and components including refurbishment and renovation materials and components.

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

Existing buildings have been designed for a certain performance, but the rules how to take actual performances of materials or components (when they are out of date, or aging or repaired and renovated many times) in account should be clarified. Standard about core rules for the product category of construction products, EN 15804, gives the EPD types with respect to life cycle stages covered. In the case “cradle to grave” all life cycle stages are covered to the assessment: 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).

Building level standards

CEN Technical Committee CEN/TC 350 has prepared standards about sustainability of construction works, which have two framework standards for building assessment: EN 15643-1:2010 and EN 15643-2:2011 and a standard about calculation method EN 15978:2011.

EN 15643-2 standard provides specific principles and requirements for the assessment of environmental performance of buildings. Assessment of environmental performance is one aspect of sustainability assessment of buildings under the general framework of EN 15643-1.

The approach to the assessment covers all stages of the building life cycle and is based on data obtained from Environmental Product Declarations (EPD), their "information modules" (prEN 15804) and other information necessary and relevant for carrying out the assessment. The assessment includes all building related construction products, processes and services, used over the life cycle of the building.

These standards are applicable for new building over their entire life cycle and for existing buildings over their remaining service life and end of life stage and are usable also for the cases of refurbishment assessment as they are.

ISO 15392:2008 Sustainability in building construction - General principles. This standard identifies and establishes general principles for sustainability in building construction. It is based on the concept of sustainable development as it applies to the life cycle of buildings and other construction works, from their inception to the end of life. The standard is applicable to buildings and other construction works individually and collectively, as well as to the materials, products, services and processes related to the life cycle of buildings and other construction works.

ISO 21931-1:2010[42] Sustainability in building construction identifies and describes issues to be taken into account in the development and use of methods in assessing the environmental performance of buildings, both new and existing.

The standards are valid for building operation, for retrofitting and refurbishment and can be used for benchmarking performance and monitoring progress towards improvement and sustainable development.

ISO 21929-1-2011 establishes a core set of indicators which provide measures to express the contribution of buildings to sustainability and sustainable development. These are Emissions to air, Use of non-renewable resources, Fresh water consumption, Waste generation, Change of land use, Access to services, Accessibility, Indoor conditions and air quality, Adaptability, Costs, Maintainability, Safety, Serviceability, and Aesthetic quality. These criteria are also relevant for assessing building refurbishment works.

<u>Service life assessment</u>

Service life assessment is an important part for life cycle assessment of new buildings. The assessment for building materials bases upon the service life planning standard ISO 15686 which includes the following parts:

- ISO 15686-1:2011 Buildings and constructed assets – Service life planning: Part 1: General principles
- ISO 15686-2:2001 Buildings and constructed assets – Service life planning: Part 2, Service life prediction procedures
- ISO 15686-3:2001 Buildings and constructed assets – Service life planning: Part 3, Performance audits and reviews
- ISO 15686-5:2008 Buildings and constructed assets – Service life planning: Part 5, Whole life cycle costing
- ISO 15686-6:2004 Buildings and constructed assets – Service life planning: Part 6, Procedures for considering environmental impacts. It identifies the interface between environmental life cycle assessment and service life planning (SLP).

42 ISO 21931-1:2010 Framework for methods of assessment of the environmental performance of construction works, Part 1: Buildings.

- ISO 15686-7:2006 Buildings and constructed assets – Service life planning: Part 7, Performance evaluation for feedback of service life data from practise
- ISO 15686-8 Buildings and constructed assets – Service life planning: Part 8, Reference service life
- ISO 15686-9:2008 Buildings and constructed assets – Service life planning: Part 9, Guide on service life declarations for building products
- ISO 15686-10:2010 Buildings and constructed assets – Service life planning: Part 10, serviceability.

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, we are not aware of international standards for assessing the condition of whole buildings. Such a standard could provide a framework for what, where and how to assess and report 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 envirornmental 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 the 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

The international standards and methodologies concerning Life cycle costing are as follows. As standardisation mostly concerns terms, process and calculation schemas, they may be applied both in case of new construction and in case of renovation.

- ISO 15686-5-2008, Buildings and constructed assets, Life Cycle Costing. This standard shows a globally applied technique for estimating the cost of whole buildings, systems and/or building components and materials, and for monitoring the occurred throughout the life cycle.
- CEN TC 348, Facility management. 2006. It concerns Life cycle costing by showing common European terms and definitions for facility management.

However the purpose of this committee is only to direct framework for business processes of refurbishments. Also CEN 350 (Sustainability assessment of construction works) does include principles for economic performance of buildings.

- Nordic classification system for Life Cycle Costing, Nordic Innovation Centre 2005. Nordic system was developed from the Norwegian NS 3454 standard as well as inputs from other Nordic countries. Nordic classification system did support ISO 15686-5 work being very similar to that with emphasis of energy-efficiency.
- LCC as a contribution to sustainable construction, a common methodology, Davis Langdon 2009. European Commission has developed an EU-wide LCC methodological framework for buildings and constructed assets to support the use of ISO 15686-5.
- EN 15459 (Energy performance of buildings – economic evaluation procedure for energy systems in buildings). This standard describes a method for economical calculation of heating systems. The calculation schema of EN 15459 can be applied to all kind of buildings (residential and non-residential, new and retrofit situations). EN 15459 is based on the global cost calculation method which results in a present value of all costs during a defined calculation period, taking into account the residual values of equipment with longer lifetimes. Projections for energy costs and interest rates can then be limited to the calculation period.
- The Commission has established a comparatively methodology framework for calculating cost-optimal levels of minimum energy performance requirements for new buildings and building elements. This kind of method will be set also for extensive energy-intensive renovations.

The results of case studies within SUSREF project show that refurbishment of exterior walls always must be viewed in the context of other measures to reduce heat loss, such as refurbishment of roof or floor construction, as well as repair and replacement of bad windows with high U-values.

For example following recommendations may be given according to the SUSREF case study calculations

- in case of new inner layer a moderate extra inner insulation may be life-cycle economical
- exterior insulation as a refurbishment method is favourable, achieving both low heat loss, a better thermal comfort and decreases the risk of low local indoor temperature and high relative humidity
- the economy of insulation fixed with air cap is more economical in case of wooden wall and solid cavity than in case of concrete sandwich
- the economy of insulation fixed with air cap is more economical in case of wooden wall and solid cavity than in case of concrete sandwich
- only the need for extensive renovation may be a basis to remarkable improving of energy efficiency of the building in life-cycle economical ways

As a summary for the use and development of standardisation in Life Cycle Costing of refurbishments:

- **cost breakdown structure is presented very clearly in ISO15686-5 and concretized both in Common European methodology and in EN 15459**
- **process for Life Cycle costing is presented in Common European methodology**
- **numerical values of possible profit rates, financial costs, economical supports or real rises of energy prices must not be standardized except they must be estimated locally, organisationally and/or project based.**

We don't need any new standards for life cycle costing of refurbishments but the comparatively methodology 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.

The most problematic part of Life cycle costing in case of extensive renovations is management of risks concerning need for connected works, moisture damages of renovated spaces etc. It is necessary to have an European guide for better risk management to avoid systematic faults which use to cause also extra unplanned costs in case of typical houses. This deals with possible quality management standards (chapter 2.7)

The accuracy of life cycle costing is also dependent on reliability of service life assessment (chapter 2.3).

8.3.3 European standards 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 the design of load bearing structures. When European wide structural calculations are based on Euro codes the exchange of services and products in the building industry is easier.

Correspondingly, building renovation and refurbishment, must be seen as an area of importance, which needs European wide methods and rules for assessment and design. As shown by SUSREF, refurbishment and renovation on building envelope is an area of great importance on building performance and on economical, environmental and health issues. In addition, to meet the objectives of greenhouse gas reduction, buildings have to be refurbished and fundamental changes have to be made.

SUSREF project recommends starting a European standardisation process with the aim to develop and formulate common methods for the assessment (calculation) and design of refurbishment aspects of building envelope and frame. We recommend the development of a European standard "Design for refurbishment of external walls" which describes design methods and performance criteria and their assessment methods.

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 D 2.2**
- **renovation concepts**
- **details for refurbishment (good construction practice)**
- **execution of work**
- **service life design.**

8.3.4 Construction product regulation

The Construction Product Regulation (CPR) has been adopted by European Commission in 2011 and it replaces Construction Product Directives. The adoption of CPR allowing construction products, that have been assessed against harmonised standards, to be legally placed on the market anywhere in the European Economic Area. This regulation brings CE marking mandatory to European countries. Manufacturers and importers have until July 2013 to ensure that their construction products meet the CE requirements of the new Construction Product Regulation if there is harmonized standard available and this is applicable also for renovation materials.

CE-marking

Products properties have been declared in the harmonized manner and level of performance has been declared when they are CE-marked according to a Harmonized Standard or have an European Technical Assesment.

The CE marking is based on a harmonised product standard (hEN) or a European Technical Assessment (ETA). The European Technical Assessment granted only by a member body of the European Organisation of TAB:s.

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. 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 notified body. The product-related requirements are described in the relevant technical product standard or ETA.

Technical standards for building products

The product-related requirements are described in the relevant technical product standard and for renovation and refurbishment products there are only some individual separate technical standards. 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 is developed and will be developed with new properties for the renovation and refurbishment market. There might have been needs also for new, technical standards and test methods which not described in harmonized existing product standards. 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. On the other hand manufacturer has always possibility to apply ETA.

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.

European Technical Assessment (ETA)

A European Technical Assessment (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 some or all seven Basic Requirements for construction work, as stated in the Construction Product Regulation for the construction works in which the product is installed. European Technical Assessment is the way to show level of performance for the products which don’t have relevant harmonized Standards.

The organisation of TAB:s consist of bodies (TABs) nominated by EU Member States and EFTA to issue European Technical Assessments (ETAs). The role of organisation of TABs is primarily to monitor and progress the drafting of EAD:s (European assessment Documents) and d to co-ordinate all activities relating to the issuing of ETA's.

An ETA can be granted when any of the following conditions apply:

- no relevant Harmonized Standards for the product exist
- a product deviates from the relevant Harmonized Standards.

The EAD 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 EAD is not itself a technical specification in the sense of the Construction Product Regulation, but EADs are needed as basis to issue ETA:s for the relevant product.

EAD comprises a list of the relevant Interpretative Documents, the specific requirements for the products within the meaning of the Basic Requirements[43], the test procedures and the methods of assessing and judging the results of the tests, the procedures related to the Assessment and verification of constancy of performance (earlier Attestation of Conformity). Manufacture can always make an initiative to apply ETA for product which has no harmonized standard or if the product deviated from the standard.

8.4 Recommendations for policy makers

8.4.1 Introduction

The aim of the study is to formulate recommendations for policy makers (on local, state and European level) about measures that support the sustainable refurbishment of exterior walls.

This Section report also presents background information and describes the most important existing policy instruments, the goal of which is to promote sustainable renovations of existing buildings.

The premise of the work was that an effective steering mechanism

a) has an impact on its focus area (energy performance, sustainable building...)

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[43] Basic requirements for construction work 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.

b) has support from the citizens
c) is feasible because tools needed in assessment and verification are available and accessible for all who need those
d) is feasible because guidelines and instructions needed are clear; municipalities and other authorities need clear instructions for implementation
e) has support from owners; it takes into consideration different building types and different types of owners. Owners are provided with required basic information, possibility to benchmark own facility with others and information how to improve.

The definition explains the effectiveness both directly on the bases of the impact on the issues that are wanted to be regulated and indirectly on the bases of the readiness and willingness. This indirect efficiency is important – because also in the case of regulations – the true impact may be significantly weakened if there is no good support and if tools are not available.

This Section outlines the instruments of steering in accordance with the UNEP report (Köppel et al. 2007). However, an additional group – municipal steering – is included to the list. In addition, the definitions of two groups – Economic and market based instruments and Support and information – are slightly changed.

The outline of the steering instruments is shown in Table 85.

Table 85. Outline of policy steering and municipal steering instruments.

	Instrument	Description
A	Control and regulatory instruments, Normative	Regulations and guidelines as part of building codes, Procurement regulations', Performance obligations and quotas (e.g. energy efficiency, fire safety); Appliance standards (e.g. standards that define a minimum energy efficiency level); Standards that define methods for mandatory issues (e.g. measurement method for energy performance)
B	Control and regulatory instruments, Informative	Mandatory audits; Mandatory labelling and certification programmes; Utility demand side management programmes
C	Economic and market-based instruments	Performance bases contracting (e.g. energy, carbon footprint): Cooperative procurement; Use of voluntary certificate schemes (e.g. energy efficiency); Branding
D	Fiscal instruments and incentives	Taxation; Tax exemption/reductions; Public benefit charges; Capital subsidies grants; Subsidized loans

E	Support and information	Support for the development of voluntary certification and labelling; Public leadership programmes; awareness raising education; Information campaigns; Detailed billing and disclosure programmes
F	Municipal steering, Steering actions in city planning and land use	Terms for release and tenancy rights of registered plots, Urban renewal programmes; Increased recompense of permitted building volume; District level exceptional decision on permission

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.

8.4.2 Background

Businesses need the right policy framework to achieve the necessary transformation:

> *“Business cannot develop and deploy the technologies needed on such a scale without help from government. International policy efforts must align with long-range business investment cycles. A broad and efficient mix of policies and programs targeted at mitigation and adaptation and backed by supportive regulation and governance frameworks will reduce investment uncertainty and assist business in its role.” WBCSD Business realities and opportunities*

The following list summarises the assessed effectiveness of alternative steering mechanisms with regard to the development towards sustainable building (SuPerBuildings D3.2 2011[44]):

- Normative regulatory instruments: Based on its normative character, the instrument affects directly on its focus area; is relatively easy to implement

44 Potential of sustainable building assessment methods as instruments of steering of sustainable building. SuPerBuildimgs Deliverable D3.2. 2011. http://cic.vtt.fi/superbuildings/

for new building but significantly more difficult to implement for existing building stock; the true impact depends on the selection of the required levels of performance.

- Mandatory information: The intended impact is to raise demand with help of information that enables comparisons; the impact depends on the extent of the focus area (all buildings/limited groups of buildings); it is easier to direct both to new and existing buildings than normative regulations; the impact may be significant if the focus area is wide.
- Voluntary certification schemes: The use of the instrument may become extensive if the marketing of the scheme is successful and if the relevant actors believe on the branding. The true impact on focus areas (like energy saving, reduction in GHGs, improved accessibility and access and thus improved equity of different user groups) depends on several issues. The selection of right performance levels and weighting criteria needs good understanding of local conditions. If this is missing and the chosen criteria are easy to achieve, the impact may remain insignificant. A big system with a high number of indicators may enable "playing" – users who are not interested in ambitious development but on easy credits. However, well-recognized and valued voluntary system which includes locally relevant and adequate demanding criteria may be effective in its focus area. The impact is the better, the better the system supports target setting and design in addition to labelling. More potential could be achieved if the certification results were integrated with the decision making processes of investors and insurance companies.
- Incentives and taxation: A right timing is important. The market must be ready for the intended activities (like renovations that save energy) for example in terms of the availability of needed skills and capacity. The level of tax reduction / incentive etc. has to be right in order to be attractive as well as not causing injustice for those who cannot make use of the instrument (for example because the instrument is directed only for small houses/multilevel buildings/owners...). Correctly timed and directed instrument may have an important effect and simulation on the targeted limited focus area.
- Municipal policy: The impact is different in different market segments. Municipal policy can effectively contribute to sustainability in the market segment of new residential buildings though the impact on existing residential buildings may be low. When voluntary agreements are made with regard to existing residential buildings, social housing agencies for instance can consider sustainability aspects in renovation projects. Private persons might be stimulated to improve their dwellings by financial support of municipalities.

8.4.3 European regulatory framework

8.4.3.1 Introduction

The main directives and regulations related to sustainable building and building products that have been recently published are as follows:

- Directive 2002/92/CE Energy Performance in Buildings Directive (EPBD)
- Directive 2009/125/EU establishing a framework for the setting of ecodesign requirements for energy-related products (ErP)
- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.
- Regulation (EU) No 305/2011 of the European parliament and of the council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

8.4.3.2 Construction Product Regulation (EU) No 305/2011

Construction products are subject to the rules on the free movement of goods in the European Union (EU) and the rules relating to the safety of buildings, health, durability, energy economy and the protection of the environment. CPR (2011)

- Sets out conditions for the market introduction and marketing of construction products by establishing harmonized rules on how to express the performance of construction products in relation to their essential characteristics and the use of CE marking on those products, and
- Establishes Basic Requirements for Construction Works (Annex I).

When a manufacturer decides to place a construction product on the market and that product is covered by a harmonised standard or conforms to a European Technical Assessment (ETA), it must complete a declaration of performance which contains, the following information (among other things):

- the systems of assessment and verification of constancy of performance of the product
- the intended use or uses of the product
- declared performance or at least one of the essential characteristics of the product.

Harmonised technical specifications should include testing, calculation and other means, defined within harmonised standards and European Assessment Documents for assessing performance in relation to the essential characteristics of construction products.

Harmonised technical specifications include harmonised standards. These shall be drawn up by European standardisation bodies pursuant to Directive 98/34/EC. Harmonised standards serve the purpose of defining methods and assessment criteria for construction product performance. If a product is not covered by a harmonised standard, manufacturers may request an European Assessment Documents issued by Technical Assessment Bodies (TABs).

The regulation says that

- When assessing the performance of a construction product, account should also be taken of the health and safety aspects related to its use during its entire life cycle.
- Threshold levels determined by the Commission pursuant to this Regulation should be generally recognised values for the essential characteristics of the construction product in question … and should ensure a high level of protection.
- Where applicable, the declaration of performance should be accompanied by information on the content of hazardous substances in the construction product in order to improve the possibilities for sustainable construction and to facilitate the development of environmentally-friendly products.
- The basic requirement for construction works on sustainable use of natural resources should notably take into account the recyclability of construction works, their materials and parts after demolition, the durability of construction works and the use of environmentally compatible raw and secondary materials in construction works.
- For the assessment of the sustainable use of resources and of the impact of construction works on the environment Environmental Product Declarations should be used when available.
- Wherever possible, uniform European methods should be laid down for establishing compliance with the basic requirements set out in Annex I.

Regarding the development of sustainability assessment methods for building, the specific reference to life cycle environmental quality in basic requirement 3 (hygiene, health and safety), and 7 (sustainable use of natural resources) is of particular importance. The requirement 7 has generally considered by the industry as a first and important step to incorporate sustainability into building products. There is obviously a need for standardization to assess this sustainable use of resources. Task is ongoing by CEN TC 350. These newly developed standards should find a way to interact and deal with existing regulations and initiatives requiring the assessment of sustainability of product.

The regulation gives the following basic requirements for construction products.

Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life. The basic requirements are as follows.

1. **Mechanical resistance and stability**
   The construction works must be designed and built in such a way that the loadings that are liable to act on them during their constructions and use will not lead to any of the following:
   a) collapse of the whole or part of the work
   b) major deformations to an inadmissible degree
   c) damage to other parts of the construction works or to fittings or installed equipment as a result of major deformation of the load-bearing construction
   d) damage by an event to an extent disproportionate to the original cause.
2. **Safety in case of fire**
   The construction works must be designed and built in such a way that in the event of an outbreak of fire:
   a) the load-bearing capacity of the construction can be assumed for a specific period of time
   b) the generation and spread of fire and smoke within the construction works are limited
   c) the spread of fire to neighbouring construction works is limited
   d) occupants can leave the construction works or be rescued by other means
   e) the safety of rescue teams is taken into consideration.
3. **Hygiene, health and the environment**
   The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of their workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate, during their construction, use and demolition, in particular as a result of any of the following:
   a) the giving-off of toxic gas
   b) the emissions of dangerous substances, volatile organic compounds (VOC), greenhouse gases or dangerous particles into indoor or out-door air
   c) the emission of dangerous radiation
   d) the release of dangerous substances into ground water, marine waters, surface waters or soil
   e) the release of dangerous substances into drinking water or substances which have an otherwise negative impact on drinking water
   f) faulty discharge of waste water, emission of flue gases or faulty disposal of solid or liquid waste
   g) dampness in parts of the construction works or on surfaces within the construction works.
4. **Safety and accessibility in use**
   The construction works must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in

operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, construction works must be designed and built taking into consideration accessibility and use for disabled persons.

5. **Protection against noise**
   The construction works must be designed and built in such a way that noise perceived by the occupants or people nearby is kept to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions.
6. **Energy economy and heat retention**
   The construction works and their heating, cooling, lighting and ventilation installations must be designed and built in such a way that the amount of energy they require in use shall be low, when account is taken of the occupants and of the climatic conditions of the location. Construction works must also be energy-efficient, using as little energy as possible during their construction and dismantling.
7. **Sustainable use of natural resources**
   The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:
   a) re-use or recyclability of the construction works, their materials and parts after demolition
   b) durability of the construction works
   c) use of environmentally compatible raw and secondary materials in the construction works.

This Regulation entered into force in **2011**. However, **Articles 3 to 28**, Articles 36 to 38 that set the conditions for making construction products available in the market, Articles 56 to 63, Articles 65 and 66, as well as **Annexes I that sets the basic requirements for construction works** and Annex II, III and V shall apply from **1 July 2013**.

Directive 2010/31/EU on the energy performance of buildings

The Directive on energy performance of buildings (2002/91/EC) is the main legislative instrument at EU level to achieve energy performance in buildings. Under this Directive, the Member States must apply minimum requirements as regards the energy performance of new and existing buildings, ensure the certification of their energy performance and require the regular inspection of boilers and air conditioning systems in buildings. On 18 May 2010 a recast[45] of The Directive on energy performance of buildings (2002/91/EC) was adopted in order to strengthen the energy performance requirements and to clarify and streamline some of its provisions.

The recast energy performance directive sets a target for all new buildings to be '*nearly zero-energy buildings'* by 2020. The directive also deals with existing buildings undergoing a major renovation.

"Nearly zero-energy building" means a building that has a very high energy performance (as determined in accordance with Annex I). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced onsite or nearby.

The provisions of the Directive cover energy used for space and hot water heating, cooling, ventilation, and lighting for new and existing residential and non-residential buildings.

This Directive lays down requirements as regards:

(a) the common general framework for a methodology for calculating the integrated energy performance of buildings and building units
(b) the application of minimum requirements to the energy performance of new buildings and new building units
(c) the application of minimum requirements to the energy performance of:
  - existing buildings, building units and building elements that are subject to major renovation
  - building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced; and
  - technical building systems whenever they are installed, replaced or upgraded.
(d) national plans for increasing the number of nearly zero- energy buildings
(e) energy certification of buildings or building units
(f) regular inspection of heating and air-conditioning systems in buildings and
(g) independent control systems for energy performance certificates and inspection reports.

The introduction of the recast directive states that

- Buildings account for 40% of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures

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

needed to reduce the Union's energy dependency and greenhouse gas emissions.

- Measures to improve further the energy performance of buildings should take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. These measures should not affect other requirements concerning buildings such as accessibility, safety and the intended use of the building.
- The energy performance of buildings should be calculated on the basis of a methodology, which may be differentiated at national and regional level. That includes, in addition to thermal characteristics, other factors that play an increasingly important role such as heating and air-conditioning installations, application of energy from renewable sources, passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building. The methodology for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building.
- Major renovations of existing buildings, regardless of their size, provide an opportunity to take cost-effective measures to enhance energy performance. For reasons of cost-effectiveness, it should be possible to limit the minimum energy performance requirements to the renovated parts that are most relevant for the energy performance of the building. Member States should be able to choose to define a 'major renovation' either in terms of a percentage of the surface of the building envelope or in terms of the value of the building.
- In order to provide the Commission with adequate information, Member States should draw up lists of existing and proposed measures, including those of a financial nature, other than those required by this Directive, which promote the objectives of this Directive. The existing and proposed measures listed by Member States may include, in particular, measures that aim to reduce existing legal and market barriers and encourage investments and/or other activities to increase the energy efficiency of new and existing buildings, thus potentially contributing to reducing energy poverty. Such measures could include, but should not be limited to, free or subsidised technical assistance and advice, direct subsidies, subsidised loan schemes or low interest loans, grant schemes and loan guarantee schemes. The public authorities and other institutions which provide those measures of a financial nature could link the application of such measures to the indicated energy performance and the recommendations from energy performance certificates.

Article 7 states with regard to existing buildings that

- Member States shall 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 in accordance with Article 4 in so far as this is technically, functionally and economically feasible.

- Member States shall in addition take the necessary measures to ensure that when a building element that forms part of the building envelope and has a significant impact on the energy performance of the building envelope, is retrofitted or replaced, the energy performance of the building element meets minimum energy performance requirements in so far as this is technically, functionally and economically feasible.

Article 12 states with regard to existing buildings that

- The energy performance certificate shall include recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit, unless there is no reasonable potential for such improvement compared to the energy performance requirements in force.
- The recommendations included in the energy performance certificate shall cover:
  (a) measures carried out in connection with a major renovation of the building envelope or technical building system(s) and
  (b) (measures for individual building elements independent of a major renovation of the building envelope or technical building system(s).

Member States shall adopt and publish, by 9 July 2012 at the latest, the laws, regulations and administrative provisions necessary to comply with Articles 2 to 18, and with Articles 20 and 27.

8.4.4 Recommendations

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:

(g) development and adoption of methods of consultation steering

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 (see also the recommendations given in Section x.x about the need to develop Euro codes for sustainable design of exterior walls refurbishment).

(h) 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.

(i) 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.

(j) 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.

(k) 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.

(l) 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.

References

Anon 1999. Building design guideline 471.111 [Calculation method to avoid condensation or mold growth on internal surfaces] SINTEF Building and Infrastucture.

Anon 2009. Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report for the European Commission Directorate-General Energy and Transport EC Service Contract Number TREN/D1/239-2006/S07.66640. Karlsruhe/Grenoble/ Rome/Vienna/Wuppertal, 15. March 2009, revised.

Almusaed, A. 2011. Biophilic and Bioclimatic Architecture Parts 1 and 2, 2011. Available at Springerlink.

ASHRAE Standard 160P-Criteria for Moisture Control Design Analysis in Buildings. Author: Anton TenWolde. ASHRAE Transactions 12/2008. Vol: 114 ISSN: 0001-2505. Start Page: 167.

ASHRAE 2009. ANSI/ASHRAE Standard 160, Criteria for Moisture Design Analysis in Buildings.

BASF. Micronal® PCM – Intelligent Temperature Management for Buildings, 2011. Available at: www.micronal.de.

Boermans, T. & Petersdorff, C. et. al. 2007. U-values For Better Energy Performance Of Buildings. Report established by ECOFYS for EURIMA.

Bragança, L., Almeida, M. & Mateus, R. 2007. Technical Improvement of Housing Envelopes in Portugal, In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. IOS Press.

Brunoro, S. Technical Improvement of Housing Envelopes in Italy, In: COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs.

CEN/TR 15941. 2010. Sustainability of construction works – Environmental product declarations – Methodology for selection and use of generic data.

Chan, H.-J., Riffat, S.B. & Zhu, J. 2010. Review of passive solar heating and cooling technologies. Renewable and Sustainable Energy Reviews, 14, pp. 781–789.

Clarke, J.A., Johnstone, C.M., Kelly, N.J., Mclean, R.C., Anderson, J.A., Rowan N.J. & Smith, J.E. 1998. A technique for prediction of the conditions leading to mould growth in buildings. Building and Environment, 34, pp. 515–521.

Eder, W., Ege, M.J., & von Mutius, E. 2006. The Asthma Epidemic. New England. Journal of Medcine. 355 (21), pp. 2226–2235.

Eichhammer et al. 2009. Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report. 2009. Authors Wolfgang Eichhammer, Tobias Fleiter, Barbara Schlomann, Stefano Faberi, Michela Fioretto, Nicola Piccioni, Stefan Lechtenböhmer, Andreas Schüring and Gustav Resch.

Eicker, U. 2003. Solar Technologies for Buildings. 330 p., Wiley.

EN ISO 13788. 2001. Hygrothermal performance of building components and building elements – Internal surface temperature to avoid critical surface humidity and interstitial condensation – Calculation methods.

EN 15026. 2007. Hygrothermal Performance Of Building Components And Building Elements – Assessment Of Moisture Transfer By Numerical Simulation.

EN 15251. 2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

EN 15643-1. 2010. Sustainability of construction works – Sustainability assessment of buildings – Part 1: General framework.

EN 15643-2. 2011. Sustainability of construction works – Assessment of buildings – Part 2: Framework for the assessment of environmental performance.

EN 15643-3. 2012. Sustainability of construction works – Assessment of buildings – Part 3: Framework for the assessment of social performance.

EN 15643-4. 2012. Sustainability of construction works – Assessment of buildings – Part 4: Framework for the assessment of economic performance.

EN 15804. 2012. Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.

EN 15942. 2011. Sustainability of construction works – Environmental product declarations – Communication format, Business to Business.

EN 15978. 2011. Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method.

Energy Saving Trust (EST), CE97. 2005. Advanced insulation in housing refurbishment: A guide for specifiers, energy consultants, housing associations and local authorities and all involved in housing refurbishment.

Energy Saving Trust (EST), CE254. 2007. Cavity wall insulation in existing dwellings: A guide for specifiers and advisors.

Fagerlund, G. 1972. Kritiska vattenmättnadsgrader ved frysning av porøsa och spröda bygnadsmaterialer. Sverige, LTH-BML. Rapport 34.

Fagerlund, G. 1977. The critical degree of saturation method of assessing the freze/thaw resistance of concrete. Tentative RILEM recommendation. Prepared on behalf of RILEM Committee 4 CDC. Materiaux et Constructions 1977, No. 58, pp. 217–229.

Geving, S. & Thue, J.V. 2002. Fukt i bygninger. Byggforsk, Oslo. ISBN 82-536-0747-4.

GLASSX. GLASSX®crystal – The glass that stores, heats and cools. 2011. Available at: http://glassx.ch/fileadmin/pdf/Broschuere_online_en.pdf.

Groleau, D., Allard, F., Gurracino, G. & Peuportier, B. 2007. Technical Improvement of Housing Envelopes in France. In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. IOS Press.

Hens, H.L.S.C. 1999. Fungal defacement in buildings: A performance related approach. International Journal of Heating, Ventilation, Air-Conditioning and Refrigerating Research, Vol. 5, H 3, pp. 256–280.

Hukka, A. & Viitanen, H. 1999. A mathematical model of mould growth on wooden material. Wood Science and Technology, Vol. 33, No. 6, pp. 475–485.

Häkkinen, T., Vares, S. & Pulakka, S. 2010. Environmental and overall sustainability aspects of external wall refurbishments. SUSREF deliverable D5.1. Available from http://cic.vtt.fi/susref/sites/default/files/D5.1_Final.pdf. Accessed October 2010.

International Energy Agency (IEA). 2010. Solar Heating and Cooling Programme, Advanced and Sustainable Housing Renovation: – A guide for Designers and Planners. Available at: http://www.iea-shc.org/publications/downloads/Advanced_and_Sustainable_Housing_Renovation.pdf

IPCC 2006. Guidelines for National Greenhouse Gas Inventories. Vol. 2. Energy. 2006. Chapter 2 Stationary combustion http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html.

ISO 9223. 1992. Corrosion of metals and alloys – Corrosivity of atmospheres – Classification.

ISO 14020. 2000. Environmental labels and declarations – General principles.

ISO 14040. 2006. Environmental management. Life cycle assessment. Principles and framework.

ISO 14044. 2006. Environmental management. Life cycle assessment. Requirements and guidelines.

ISO 14025. 2000. Environmental labels and declarations – Type III environmental declarations – Principles and procedures.

ISO 15392. 2008. Sustainability in building construction – General principles.

ISO 15686-6. 2008. Buildings and constructed assets. Life Cycle Costing.

ISO 21929. 2011. Sustainability in building construction – Sustainability indicators. Part 1 – Framework for the development of indicators and a core set of indicators for buildings.

ISO 21930. 2007. Sustainability in building construction – Environmental declaration of building products.

Itard et al. 2008. Building Renovation and Modernisation in Europe: State of the art review. Authors Laure Itard (OTB), Frits Meijer (OTB), Evert Vrins & Harry Hoiting (W/E). Final report.

Knaack, U., Klein, T., Bilow, M. & Auer, T. 2007. Façades – Principles of Construction. Available at SpringerLink.

Koukkari, H. & Braganca, L. 2009. Updated COST C25 review. Towards energy-efficient buildings in Europe. Authors Heli Koukkari and Luís Bragança. 18 p.

Köppel, S. & Ürge-Vorsatz, D. 2007. Assessment of policy instruments for reducing greenhouse emissions from buildings. Report for the UNEP SBCI. 81 p.

Künzel, H., Künzel, H.M. & Sedlbauer, K. 2006. Long-term performance of external thermal insulation systems (ETICS). Architectura 5 (1), pp. 11–24.

Langdon 2007. LCC as a contribution to sustainable construction, a common methodology. Davis Langdon & Co. 2007.

Langdon 2010. Development of a promotional campaign for life Cycle Costing in construction. Davis Langdon & Co 2010.

Matuska, T. & Sourek, B. 2006. Façade solar collectors. Solar Energy, 80, pp. 1443–1452.

Mehling, H. & Cabeza, L.F. 2008. Heat and cold storage with PCM – An up to date introduction into basics and applications. Available at SpringerLink.

Naticchia, B., D'Orazio, M., Carbonari, A. & Persico, I. 2010. Energy performance of a novel evaporative cooling technique. Energy and Buildings, 42, pp. 1926–1938.

Møller, E.B. 2003. Hygrothermal performance and soiling of exterior building surfaces. PhD Thesis. Report R-068. Technical University of Denmark, Department of Civil Engineering.

Nemry et al. 2008. IMPRO-buildings. 2008. Environmental Improvement Potentials of Residential Buildings (IMPRO-Building). JRC Scientific and technical reports. EUR 23493 EN – 2008 ftp://139.191.159.34/pub/EURdoc/JRC46667.pdf Autors: Francoise Nemrt, Andreas Uihlein, Cecilia Makishi, Bastian Wittstock, Anna Brausen, Chritian Wetzel, Ivana Hasan, Sigrid Niemeier, Yosrea Frech, Johannes Kreissig, Nicole Gallon.

Ojanen, T., Viitanen, H., Peuhkuri, R., Lähdesmäki, K., Vinha, J. & Salminen, K. 2010. Mould growth modeling of building structures using sensitivity classes of materials. Proceedings of Thermal Performance of the Exterior Envelopes of Whole Buildings XI. Clearwater Beach. December 2010.

Peel, M.C., Finlayson, B.L. & McMahon, T.A. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci., 11, pp. 1633–1644.

Petersdorff, C., Boermans, T., Joosen, S., Kolacz, I., Jakubowska, B., Scharte, M., Stobbe, O. & Harnisch, J. 2005. Cost-Effective Climate Protection in the Building Stock of the New EU Member States. Beyond the EU Energy Performance of Buildings Directive. Report established by ECOFYS for EURIMA. 78 p.

Petersdorff, C., Boermans, T. & Harnisch, J. 2006. Mitigation of CO2 Emissions from the EU-15 Building stock. Beyond the EU Directive on the Energy Performance of Buildings. Report established by ECOFYS for EURIMA. 2004. 36 p. (Petersdorff et al. 2004) and Mitigation of CO2 Emissions from the EU-15 Building stock. Beyond the EU Directive on the Energy Performance of Buildings. Environ Sci Pollut Res., 13, (5), pp. 350–358 (2006).

Plewako, Z., Kozlowski, A. & Rybka, A. 2007. Technical Improvement of Housing Envelopes in Poland, In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. IOS Press.

Prupim Developments. 2011. Sustainable Refurbishment: A Framework For Decision Making. Edition 1. Available from http://www.prupim.com/upload/managerFile/3483_PRUPIM_Sustainable_Refurbishment.pdf. Accessed March 2011.

Ravesloot, C.M. 2007. Technical Improvement of Housing Envelopes in the Netherland, In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. IOS Press.

RIBA Publications. 2010. RIBA Plan of Work. Available from http://www.pedr.co.uk/textpage.asp?menu=1a&sortorder=130&area=main. Accessed May 2011.

Scanvac. 1990. [Class-divided indoor climate system. Guidelines and specifications]. Swedish Indoor Climate Institute, Stockholm. Report R1. ISBN 82-90033-17-6.

Schüring, A. & Lechtenböhmer, S. 2008. Energy Efficiency Potentials of Building Shell Oriented Measures in Residential Buildings in the EU. Wuppertal Institute contribution to ICCR Workshop, Innovative Concepts and Technologies for Energy Efficiency in the Building Sector", 28th May 2008 in Brussels.

Sedlbauer, K. 2001. Prediction of mould fungus formation on the surface of/and inside building components. University of Stuttgart, Fraunhofer Institute for building Pgysics, Thesis. Stuttgart. Germany.

Sedlbauer, K., Künzel, H.M. & Holm, A.H. 2004. Predicting Indoor Temperature and Humidity Conditions Including Hygrothermal Interactions with the Building Envelope. ASHRAE Transactions Vol. 110, Start Page 820. ISSN: 0001-2505 06/2004.

Soimakallio, S., Kiviluoma, J. & Saikku, L. 2011. The complexity and challenges of determining GHG (greenhouse gas) emissions from grid electricity consumption and conservation in LCA (life cycle assessment). A methodological review. Energy, 36(2011), pp. 6705–6713.

NS 8175. 2009. Standards Norway [Sound conditions in buildings]. (in Norwegian). Standards Norway, Lysaker.

StoSolar – Die solare Wandheuzung. Available at: *http://www.sto.at/evo/web/sto/33144_DE-Infomaterial_Sto_Ges.m.b.H.-StoSolar_Fassadenelemente.pdf*

Trpevski, S. 2007. Technical Improvement of Housing Envelopes in the F.Y.R. of Macedonia. In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. Research in Architectural Engineering Series, Volume 5, pp. 83–94. ISBN 978-1-58603-737-6.

Valesan, M. & Sattler, M.A. 2008. Green Walls and their Contribution to Environmental Comfort: Environmental Perception in a Residential Building. Presented at: PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008.

Vesikari, E. 1999. Prediction of service life of concrete structures with regard to frost attack by computer simulation. Proc. Nordic Sem. on Frost Resistance of Building Materials, Aug. 31–Sept. 1 1999, Lund. Lund Institute of Technology, Division of Building materials. 13 p.

Vesikari, E. & Ferreira, M. 2011. Frost deterioration process and interaction with carbonation and chloride penetration – Analysis and modeling of test results. Technical Research Centre of Finland. VTT Research Report. 44 p.

Wetzel, C. & Vogdt, F.-U. 2007. Technical Improvement of Housing Envelopes in Germany, In: L. Bragança, C. Wetzel, V. Buhagiar, L.G.W. Verhoef (eds.). COST C16 Improving the Quality of Existing Urban Building Envelopes – Facades and Roofs. IOS Press.

WHO 2002. World Health report 2002. http://www.who.int/entity/whr/2002/en/whr02_en.pdf

WHO 2005. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.

WHO 2007. Indoor air. National burden of disease estimate. http://www.who.int/indoorair/publications/indoor_air_national_burden_estimate_revised.pdf.

WHO 2009. http://whqlibdoc.who.int/publications/2009/9789241547673_eng.pdf (RADON HANDBOOOK)

Viitanen, H. 1996. Factors affecting the development of mould and brown rot decay in wooden material and wooden structures. Effect of humidity, temperature and exposure time. Doctoral Thesis. Uppsala. The Swedish University of Agricultural Sciences, Department of Forest Products. 58 p

Viitanen, H., Hanhijärvi, A., Hukka, A. & Koskela, K. Modelling mould growth and decay damages In: Seppänen, O. & Säteri, J. (ed). Healthy Buildings 2000. Vol. 4, FiSIAQ, pp. 341–346.

Viitanen, H. Toratti, T., Makkonen, L., Peuhkuri, R., Ojanen, T., Ruokolainen, L. & Räisänen, J. 2010. Towards modelling of decay risk of wooden materials. European Journal of Wood and Wood Products. Vol. 68, No. 3, pp. 303–313.

Viitanen, H., Ojanen, T., Peuhkuri, R., Vinha, J., Lähdesmäki, K. & Salminen, K. 2011. Mould growth modelling to evaluate durability of materials. Proc

12th Int Conf on Durability of Building Materials and Components (DBMC). Porto, Portugal, April 12th–15th, 2011. 8 p.

Yun, G.Y., McEvoy, M. & Seemers, K. 2007. Design and overall energy performance of a ventilated photovoltaic façade. Solar energy 81, pp. 383–394.

Yun, G.Y. & Seemers, K. 2009. Implications of urban settings for the design of photovoltaic and conventional façades. Solar Energy, Vol. 83, Issue 1, pp. 69–80.

Appendix A: Examples of environmental data for building products

Insulation materials

Rock wool

Source of information	Environmental declarations formulated according to the Finnish national system http://www.rts.fi from cradle to gate	Environmental declarations according to epd-norge.no 131E Including product transportation
Use of renewable energy (MJ/kg)	1.4	0.91 + 2.59 = 3.5
Use of non-renewable energy (MJ/kg)	13	14.03
Use of renewable natural raw materials (kg/kg)	0.194	
Use of non-renewable natural raw materials (kg/kg)	1.78 (mineral)	0.777 (mineral) + 0.065+0.111+0.476 (fossil) = 1.32
Greenhouse gas emissions (g/kg)	970+25x0.70+298x0.018 = 993	1200 + 25x0.88+298x0.02 = 1228
Wastes (other wastes + problem wastes) (g/kg)		45
Density kg/m^3	22–250	32

Glass wool

Source of information	Environmental declaration according to NF P01 010 Data received from manufacturer (Isover) Note: transportation (150 km) of product is included.
Use of renewable energy (MJ/kg)	5.66
Use of non-renewable energy (MJ/kg)	29.1
Greenhouse gas emissions (g/kg)	1512

Expanded polystyrene

Low molecular mass hydrocarbons, usually pentane, are incorporated into the finished resin in the manufacture of expandable polystyrene (EPS). These additives vaporise during subsequent processing to produce foam. This eco-profile covers the manufacture of EPS and assumes that 6% of mass is vaporised during the manufacture of expanded PS.

Source of information	APME (ELCD)
Use of renewable energy (MJ/kg)	1.47
Use of non-renewable energy (MJ/kg)	99.8
Use of renewable natural raw materials (kg/kg)	0
Use of non-renewable natural raw materials (kg/kg)	1.19
Greenhouse gas emissions (g/kg)	3510
Wastes (other wastes + problem wastes) (g/kg)	120

PUR

The environmental profile of rigid polyurethane is based on the information of precursors (polyols and diisocyanates (diphenylmethane diisocyanate, MDI)). The model calculation considers the production of a rigid PUR-foam blown with pentane and transportation of raw materials.

Source of information	APME (ELCD)
Use of renewable energy (MJ/kg)	0.72
Use of non-renewable energy (MJ/kg)	104
Use of renewable natural raw materials (kg/kg)	0.00097
Use of non-renewable natural raw materials (kg/kg)	1.43 (mineral) + 2.11 (fossil)
Greenhouse gas emissions (g/kg)	4200
Wastes (other wastes + problem wastes) (g/kg)	218 + 27.7 (chemicals)

PUR and phenolic

The environmental profile of urethane and phenolic insulation based on the BRE Global generic data.

Source of information	Phenolic 35 kg/m^3 59 mm 0.02 W/m K	Urethane 32 kg/m^3 66 mm 0.022 W/m K
Use of fossil energy (MJ/m^2)	150	190
Use of mineral natural raw materials (kg/m^2)	1.3	3.2
Greenhouse gas emissions (kg/m^2)	6.3	9.9

Claddings and frame structures

Hot-dip galvanized facade claddings

Source of information	Environmental declarations formulated according to the Finnish national system (2010) Created for Rautaruukki http://www.rts.fi
Use of renewable energy (MJ/kg)	1.8
Use of non-renewable energy (MJ/kg)	16.8
Use of renewable natural raw materials (kg/kg)	0
Use of non-renewable natural raw materials (kg/kg)	0.650
Greenhouse gas emissions (g/kg)	1010+25x1.1+ 298x0.0078 = 1040
Wastes (other wastes + problem wastes) (g/kg)	260 + 1.1
Density kg/m^3	7850

Paint coated facade steel claddings

Source of information	Environmental declarations formulated according to the Finnish national system (2010) Created for Rautaruukki http://www.rts.fi
Use of renewable energy (MJ/kg)	2.2
Use of non-renewable energy (MJ/kg)	18.5
Use of renewable natural raw materials (kg/kg)	0
Use of non-renewable natural raw materials (kg/kg)	0.650
Greenhouse gas emissions (g/kg)	1150+25x1.2+ 298x0.0110 = 1180
Wastes (other wastes + problem wastes) (g/kg)	265 + 2.9
Density kg/m^3	7850

Sawn timber

	Sawn dried timber and structural timber (crude wood)		
Source of information	Environmental declarations formulated according to the Finnish national system (2010) http://www.rts.fi Note: Carbon bound in wood * Feedstock energy of wood is not included in the figures Per kg of shipping dry sawn timber	Environmental declarations according to epd-norge.no 082E Including transportation of product Per m^3	Environmental declarations according to epd-norge.no 082E Including transportation of product Per m^3
Use of renewable energy	2.9 MJ/kg	1393 MJ/m3 + 7200 MJ/m3 (feedstock)	1521 MJ/m3
Use of non-renewable energy	1.4 MJ/kg	315.53 + 3.87 MJ/m3 (feedstock)	438 MJ/m3
Use of renewable natural raw materials	1.13 kg/kg	1.17 m3/m3	1.22 m3/m3 (timber + bark)
Use of non-renewable natural raw materials	0.0047 kg/kg	7.23 (fossil) + 1.75 (others) kg/m3	10.9 (fossil) + 3.11 (others) kg/m3
Greenhouse gas emissions	65+25x0.21+ 298x0.000008= 70.3 g/kg	160709 + 25x27.1 + 298x5.65 =19070 g/m3	28 920 g/m3
Wastes (other wastes + problem wastes)	1.7+2.0 g/kg	2.08 + 3.72 kg/m3	2.743 + 4.431 kg/m^3
Density kg/m^3	417 (pine) 366 (spruce) (dry)		
Moisture content (%)	The moisture content of the shipping dry sawn timber was 18% of the dry matter in the calculations	10–14, 14–18, 18–20%	10–14, 14–18, 18–20%

* The amount of carbon dioxide stored in the sawn timber is 1.55kg/kg of shipping dry sawn timber.

Steel framework

Source of information	Environmental declarations formulated according to the Finnish national system Created for Rautaruukki http://www.rts.fi (2010)	Environmental declarations according to epd-norge.no 079 Created for Contiga AS Per kg building frame
Use of renewable energy	2 MJ/kg	9.21 MJ/kg
Use of non-renewable energy	16 MJ/kg	10.6 MJ/kg
Use of renewable natural raw materials		0.0029 MJ/kg
Use of non-renewable natural raw materials	0.20 kg/kg (excluding fossil)	0.22 (fossil) + 0.20 (others) kg/kg (excluding recycled scrap)
Greenhouse gas emissions	1070+25x0.8+298x0.006 = 1092 g/kg	756 g/kg
Wastes (other wastes + problem wastes)	0.290 + 0.0012 kg/kg	0.271 + 0.00181 kg/kg
Density kg/m^3	7850 kg/m3	

Concrete cladding element

Source of information	Environmental declarations formulated according to the Finnish national system http://www.rts.fi (2010)
Use of renewable energy (MJ/kg)	0.20
Use of non-renewable energy (MJ/kg)	2.6
Use of renewable natural raw materials (kg/kg)	0.00667
Use of non-renewable natural raw materials (kg/kg)	1.08
Greenhouse gas emissions (g/kg)	240+25x0.44+298x0.043 = 264
Wastes (other wastes + problem wastes) (g/kg)	12+0.00000067
Density kg/m^3	2480

Fibre glass reinforced polymer composite panels (exterior facade panel)

	Fibre glass reinforced polymer composite panels covered with acrylic (exterior facade panel)
Source of information	Environmental declarations according to epd-norge.no 096 Created for Steni Colour Including transportation of product
Use of renewable energy	13.0 MJ/m2
Use of non-renewable energy	13.4 MJ/m2
Use of renewable natural raw materials	
Use of non-renewable natural raw materials	32.7 kg/m2
Greenhouse gas emissions	3.02 kg/m2
Wastes (other wastes + problem wastes)	14 + 0.0075
Thickness (mm)	- 7.0

Building boards

Building boards

	Gypsum cardboards		Fibre boards
Source of information	Environmental declarations formulated according to the Finnish national system Created for Saint Gobain http://www.rts.fi	Environmental declarations according to epd-norge.no 107 Created for Norgips	Environmental declarations formulated according to the Finnish national system Created for Suomen kuitulevy http://www.rts.fi
Use of renewable energy (MJ/kg)	0.3 MJ/kg	6.53 MJ/m^2	6.8 + 20 (feedstock) MJ/kg
Use of non-renewable energy (MJ/kg)	6.4 MJ/kg	27.7 MJ/m^2	6.2 + 0.064 (feedstock) MJ/kg
Use of renewable natural raw materials (kg/kg)	0.0307	0.732 kg/m^2	1370 g/kg
Use of non-renewable natural raw materials	1.15 (excluding fossil)	8.39 (other) + 0.00405 (fossil) kg/m^2	320 g/kg
Green house gas emissions	360 + 25x1+298x0.0036 = 386 g/kg	2.02 kg/m^2	400+25x0.74+298x0.021 = 425 g/kg
Wastes (other wastes + problem wastes)	140 + 0.076 g/kg	0.0252 + 0.00023 kg/m^2	1.4 + 0.066 g/kg
Density			300 kg/m^3
Weight	9 kg/m^2 11.7 kg/m^2		3.0 kg/m^2 (10 mm) 3.6 kg/m^2 (12 mm) 6.6 kg/m^2 (22 mm) 7.5 kg/m^2 (25 mm)
Thickness	13 mm	9.5 mm	

Appendix B: Environmental impacts of refurbishment concepts – basic method for assessment

An example about the basic approach when assessing the environmental impacts of a refurbishment concept

The calculation is done for a concrete element wall that was typical in multi storey residential buildings 1960s and 1970s.

In this example the starting point is a wall structure which consists originally of

- interior rendering
- load bearing concrete wall, thickness 100 mm, reinforced with steel bars
- heat insulation, mineral wool, thickness 100 mm
- exterior concrete wall, thickness 80 mm, reinforced with stainless steel bars
- sealing strip
- U value 0.40 W/m^2 K.

In order to improve the heat insulation of the wall and the energy performance of the building, the refurbishment is done in such a way that the exterior concrete wall and the heat insulation are removed and a new thicker insulation and new exterior concrete wall are added. Here it is assumed that the intended new U-value is 0.17 W/m^2 K which requires an insulation thickness of 200 mm (mineral wool, λ value 0.035 W/m K). The exterior concrete wall is similar to the original wall.

The environmental impacts because of this refurbishment concepts come from

- demolition and disposal of concrete and heat insulation layers
- manufacture (from cradle to gate) and transportation of new replacing products (exterior concrete wall + heat insulation)
- construction of the new structure considering the material losses.

The example is calculated with using the Finnish values. The outcome for the refurbishment is as follows:

- CO_2 51.0 kg/m^2
- CH_4 61.0 g/m^2
- N_2O 14.7 g/m^2
- non-renewable energy (embodied) 491 MJ/m^2
- non-renewable materials 226 kg/m^2.

When studying alternative refurbishment concepts, the corresponding values should be calculated for all alternatives.

In addition, we may consider the effect of the improved U-value on the thermal transmission. The thermal transmission can be calculated with help of the following equation:

$Q_t = H_t * (T_i - T_o) * \Delta t / 1000$,

where H_t is characteristic thermal loss of the building part, W/K,
Ti is indoor temperature °C,
To is outdoor temperature °C,
Δt is the period of time.

Tables 25 and 26 present the calculation results for these wall structures. The chosen location in is Helsinki and the chosen time period is 50 years.

Thermal transmission for 1 m2 of wall (location Helsinki).

	Time	Indoor temperature	Outdoor temperature	U value 0.17 Wm^2/K	U value 0.40 Wm^2/K
	h	°C	°C	kWh/m^2	kWh/m^2
January	744	20	-6.1	3.3	7.77
February	672	20	-6.6	3.0	7.15
March	744	20	-3.5	3.0	6.99
April	720	20	2.6	2.1	5.01
May	744	20	8.9	1.4	3.30
June	720	20	14	0.7	1.73
July	744	20	17.2	0.4	0.83
August	744	20	16	0.5	1.19
September	720	20	11.1	1.1	2.56
October	744	20	5.4	1.8	4.34
November	720	20	1	2.3	5.47
December	744	20	-2.6	2.9	6.73
Whole year	8760	240	57.4	22.6	53.1

In order to interpret the results in terms of emissions, we have to make assumptions about the sources of heating energy. Table 21 shows the results for two cases: 1) Helsinki district heat, 2) Finnish average electricity. The primary energy consumption and the GHGs have been calculated for a total time period of 50 years and for a wall structure the U value of which is 0,40 Wm^2/K.

Assessed environmental impact for a wall (U value 0.17.

Energy loss because of thermal transmission	Non-renewable materials	Non-renewable energy	GHGs
kWh/m^2 50 a	kg/m^2 50 a	MJ/m^2 50a	kg/m^2 50a
1128	81	3 722	237

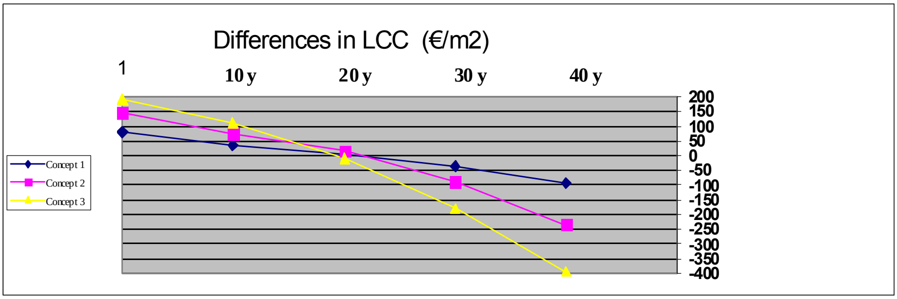
Appendix C: Examples of LCC calculations for alternative renovation concepts

Examples on assessed renovation concepts

Action	Renovation concept 1	Renovation concept 2	Renovation concept 3
	Renewing of windows and ventilation system, setting an effective heat recovery system and improving tightness.	Improving tightness and insulation of envelope, renewing windows and HVAC systems.	Improving tightness and insulation of envelope, life cycle optimized renewing of windows and HVAC systems.
Improving tightness and insulation of envelope	-5%	-15%	-25%
Renewing of windows and doors	-10%	-10%	-15%
Renewing of HVAC systems	-10%	-25%	-35%
Total	**-25%**	**-50%**	**-75%**

Case example: Economy of energy saving renovation concepts

Renovation of an old block of flats			**Renovation concept 1**	**Renovation concept 2**	**Renovation concept 3**
Cost level:	1/2009				
Heating way:	district heating				
Calculation cycle:	40 y (→ year 2050)				
Starting price of heating energy:	0.05 €/kWh				
Starting price of electricity energy:	0.10 €/kWh				
Real rise of energy price:	3%/y				
ECOEFFICIENCY		**Basis**			
Heating	kWh/m^2/y	200	150	100	50
Electricity	kWh/m^2/y	10	12	9	6
Inner climate class		S3	S2	S2	S2
Energy class		F	D	B	A
CO_2	tn/m^2/40 y	2.2	1.7	1.2	0.7
LIFE CYCLE ECONOMY (present value)			Cost diff €/m^2	Cost diff €/m^2	Cost diff €/m^2
Diffences in building cost		**B**	**+80**	**+145**	**+190**
Improving insulation of envelope			0	+40	+70
Renewing of windows and doors			+30	+45	+60
Improving tightness			+15	+40	+50
Ventilation parts			+35	+35	+40
Heating parts				-15	-30
Differences in maintenance cost		**M**	**+10**	**+25**	**+20**
Difference in heating cost		**H**	**-195**	**-390**	**-585**
Difference in electricity cost		**E**	**+10**	**-15**	**-20**
Difference in Life Cycle Cost		**B+M+H+E**	**-95**	**-235**	**-395**
Price of loan money			**+30**	**+65**	**+85**
Investment support			**-50**	**-50**	**-50**
Difference in Life Cycle Cost (indirect)			**-115**	**-220**	**-360**
Pay back time years			**21**	**20**	**18**
Difference in Resale value			**+3…+5**	**+5….+10**	**+10…+15**


Differences in LCC (€/m2)
1
10 y
20 y
30 y
40 y
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
Concept 1
Concept 2
Concept 3

Appendix D: GUIDELINES – Procedure for the calculation hygrothermal performance with an assessment example

The following guidelines are relevant when analysing the hygrothermal performance of the existing constructions and when finding sustainable refurbishment solutions for these. The simulations in these guidelines are assumed to be performed with a 1D or 2D hygrothermal simulation program like WUFI, which solves the dynamic, coupled temperature and moisture conditions in a construction and can e.g. take into account the amount of water absorbed to construction due to the driving rain (see Chapter 3.5.2).

NOTE: These guidelines do not recommend use of any specific software. WUFI is just used as an example as it is a rather common tool and includes most of the features needed for the analysis.

If only thermal 2D/3D calculations are performed – e.g. with HEAT2 or Therm – (which are normally sufficient for studying effects of thermal bridges), a method described in EN ISO 13788 for calculation of critical temperatures of internal surfaces can be used for assessing the potential for mould growth.

These guidelines gather and supply information in the related excel data sheet for documentation of the calculations and results. A data sheet example is found in Appendix 4.

Description of the construction

A sufficient description of the original and/or the refurbished construction is important for the documentation and understanding the performance of the analysed solutions. In this section, some examples are given, how to define and document a wall construction to be analysed.

Material layers

Typical material layers and material values for each construction type – also in 2D and 3D if relevant – should be given. These should be reported with a combination of a drawing and table, e.g. Figure 1 and Table 1 below. These should include at least following information:

- Typical material layers, typical thicknesses and typical variations of these
- Typical material values e.g. density, thermal conductivity and water vapour diffusion coefficient or resistance factor. Use suitable average material values from your software databases, if they are estimated to be representative enough, and refer to them by their name in database, e.g.

WUFI "Concrete, w/c = 0.5". Make a comment about this qualified evaluation of material parameters in your reporting.

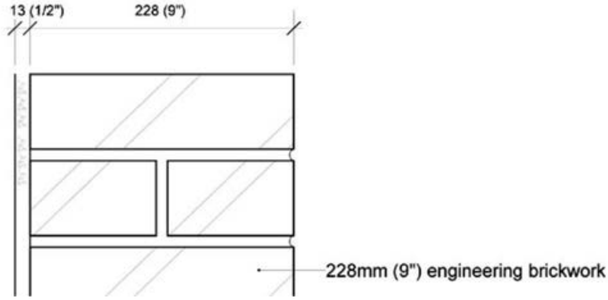


Figure 1. Example on description of a wall. The drawing should also include dimensions in vertical direction, if there are 2D effects. Regular brick walls can, in most cases, be calculated in 1D with average material properties for masonry walls.

It would be too laborious to list all the material parameters for all the materials in a table form, but including some of these basic material parameters already gives the reader of the report an idea of the material characteristics. A data sheet of all the relevant material parameters including also isotherms and other material characteristics as a function of temperature and humidity (if available) should be included in an appendix.

If using the standard materials from the database of a common simulation software e.g. WUFI, it is sufficient to only refer to the material by exact name and then give the basic values in a table form as in Table 1.

Table 1. Example on presentation of the construction material layers with material thickness and some hygrothermal parameters.

	Thickness	Bulk density	Porosity	Specific Heat Capacity, Dry	Thermal conductivity	Water vapour diffusion resistance
	d	ρ	p	c_p	λ	μ
	m	[kg/m³]	[m³/m³]	[J/kgK]	[W/mK]	[-]
brick	0.228	1900	0.24	850	0.6	10
interior plaster	0.013	850	0.65	850	0.2	8,.

The wall construction should be modelled as true to reality as possible with your software. Of course, simplifications cannot be totally avoided in any modelling, but these must be based on knowledge and experience in building physics. Figure 2 is the modelled version of Figure 1. Note the opposite placement of interior and exterior side in the model compared to the drawing in this example. Generally, the convention is adopted that the exterior of the construction is always shown on the left side of any cross-section.

Monitoring (= logging of state variables, typically temperature and relative humidity or moisture content, typically every hour) of the hygrothermal conditions for further analysis should be done in any location assumed critical. This means monitoring at least on the both surfaces of the construction. Also on any other material interface or cavity that is assumed critical. Document this with a drawing or "screen dump". The model drawing in Figure 2 also indicates the used calculations mesh (= numerical cells where the state variables are solved for every time step), which should be defined as fine as necessary for a correct analysis. The software manuals typically give recommendations for the mesh size.

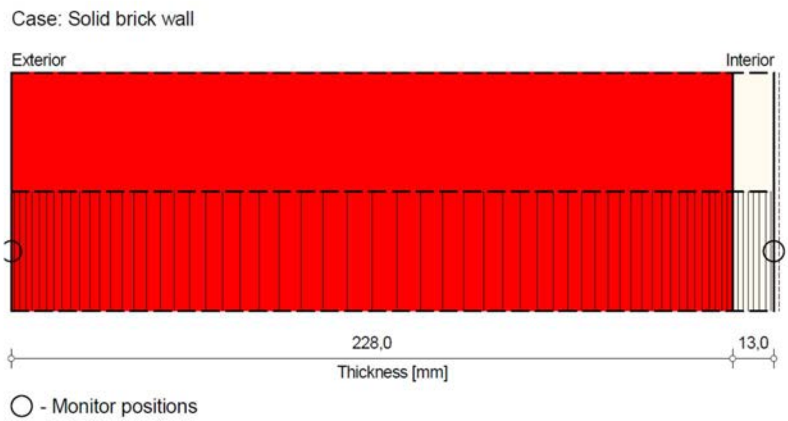


Figure 2. The modelled construction (Wufi Pro 5.0) with indication of the monitoring positions, where e.g. T and RH are logged as hourly values.

The calculated U-value of the modelled construction should be given for the further analysis work and for the presentation of the results. U-value of the example case is 1.7 W/(m^{2}K).

When describing the original construction to be refurbished, the common problems and typical deterioration mechanism for the analysed case should be reported. This can help to identify the parts of the wall that are especially critical for the hygrothermal performance of the construction. The criteria for choice of the relevant alternative refurbishment solutions depend e.g. on

- typical problems: e.g. mould growth, frost damage, air leakage
- type of building: e.g. listed or not listed
- economy, architectural ambitions, etc.

The refurbished solutions should be documented in the same way as the original ones: A drawing, description and a list of material layers with some typical material data. An example of a refurbished construction to be modelled is in Figure 3.

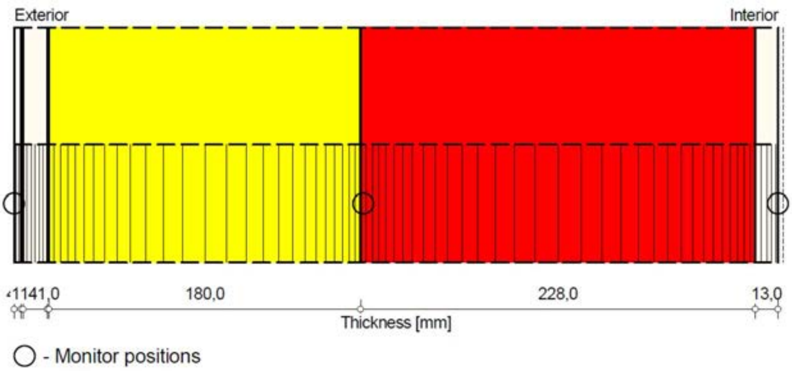


Figure 3. A model of the solid brick wall with an exterior insulating and finishing system (EIFS) of EPS and an exterior plaster system.

Construction modelled in 2D

Most of the input parameters for a problem in 2 dimensions are the same as for a problem in 1 dimension. However, the physical model of the construction is different in 2D and below figures show an example on a model for a solid granite wall. An example on analysis of a construction in 2D is found in Appendix 3.

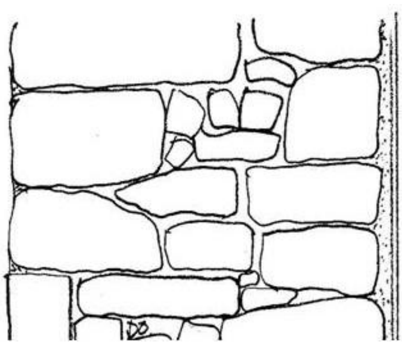


Figure 4. Cross section picture of the existing solid granite wall.

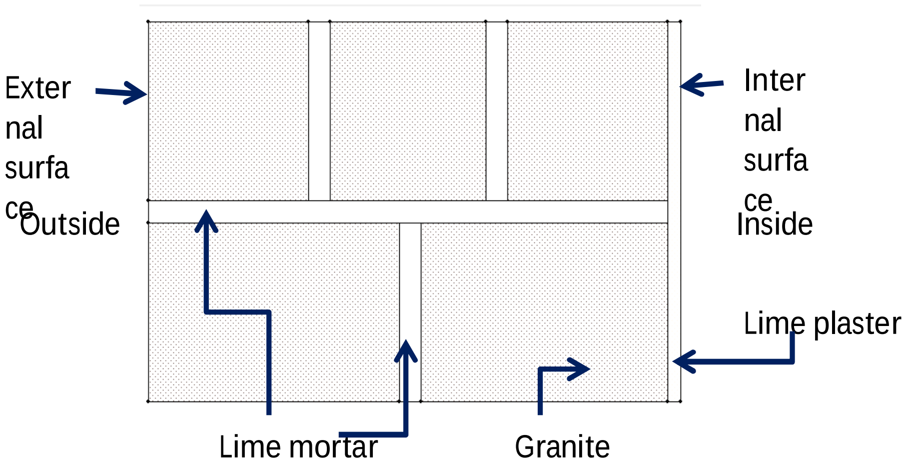


Figure 5. WUFI® 2D model of the existing solid granite wall.

The presentation of the granite wall in Figure 5 shows a very simplified presentation of the stone/mortar matrix. The grade of simplification must be carefully planned and depends on the balance between computing capacity and time and the uncertainty of other parameters, including the material parameters.

NOTE: The assessment of the 2D simulation results is identical to the method described in this report for one-dimensional hygrothermal simulation.

(Ventilated) Cavities

If there is a ventilated cavity in the construction, the effect of the ventilation should be modelled as realistic as possible. However, a true description of the heat, air and mass flow in such a cavity would require a detailed CFD model, which is unnecessary for most of the cases.

A much simpler model can give, however, a qualified presentation of the drying potential or the opposite, of the cavity. E.g. 1D WUFI (Wufi Pro) uses a simple air change rate of the cavity, where the cavity is ventilated with outdoor air with a given rate.

The calculations should be performed for at least for a case with a "standard" ventilation rate of the cavity (e.g. 50 h^{-1}). A parameter study can cover cases with a very poor ventilation rate (e.g. 1 h^{-1}) and a good ventilation rate (e.g. 100 h^{-1}).

Surface transport coefficients

The surface transport coefficients for heat and moisture should be estimated or the best standard values should be used. In some programs, these are determined dynamically as a function of wind, sun, facade colour etc. Therefore, if possible, these factors should be taken into account for the most real representation of the construction and facade orientation to be studied. Typical colours, coatings etc. should be represented. These have an effect on the radiative heat transfer properties as well as on the transport of moisture. The effective water vapour resistance of e.g. indoor painting should be estimated.

Initial moisture content

Another important parameter for the description of the construction to be studied is the assumed initial moisture content of the material layers. According to the common standards, e.g. ASHRAE[46] Guidelines, and practice, a equilibrium moisture content (EMC) corresponding to RH = 80% should be used as a standard value (= EMC80).

A higher value. e.g. EMC90 or even 2 x EMC80, or any better estimate for the actual case, for the initial moisture content should be used

- If it is known that the construction to be studied has a higher moisture content, e.g. due to driving rain on unprotected facade
- If new concrete elements or other materials having high initial moisture content are included in the refurbished solution
- When studying the general drying potential of the facade.

Description of the boundary conditions

When assessing the hygrothermal performance of the constructions, the goal is to find as true a presentation as possible of the conditions the wall construction is exposed to. However, to reveal any potential risks of moisture related problems or damage, the simulated conditions should be chosen to present a worst, but also a probable case scenario. The calculation analysis should show that the construction is robust enough both regarding the durability and the indoor air quality and comfort. In the following, some guidelines are given for choice of the exterior and interior climates for simulations.

Exterior climate

Data from a weather station representative to the analysed region and constructions should be chosen. Depending on the construction type and the typical location of this construction type, climate data from a nearest possible

46 ASHRAE Standard 160P-Criteria for Moisture Control Design Analysis in Buildings. Author: Anton TenWolde ASHRAE Transactions 12/2008. Vol: 114 ISSN: 0001-2505. Start Page: 167.

weather station should be chosen in such a way that eventual effect of e.g. strong winds (driving rain) and frost cycles around 0 °C (frost damage) is present.

Figure 6 presents a map of the overall climatic zones in Europe according to Köppen-Geiger -system. For an overall estimate, weather data from a single weather station can be used for every other location inside the same climatic zone.

However, a great variety of the climatic effects can be possible within a relatively small geographical area. The conditions for e.g. driving rain, solar radiation and air temperature in e.g. Wales and Ireland and also in the Alps and other mountain areas, can vary a lot within a small area, even a few kilometers. Therefore, depending on the actual or a probable location of the construction and the solution to be used, the necessary sensitivity analysis of the climate data should be considered. In Appendix 2 motivation for criteria for selection of an appropriate weather station for a building physical simulation is presented.

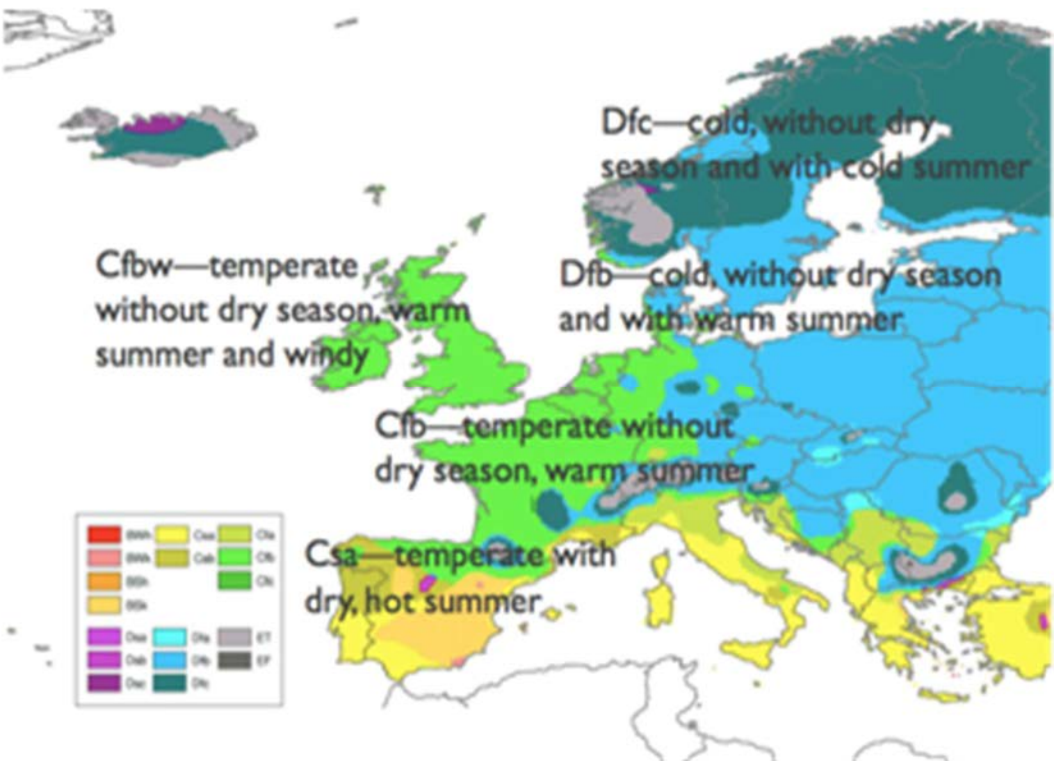


Figure 6. European climate zones according to Köppen-Geiger system.

Local exposure and compass orientation of the facade

The performance of the wall should be analysed in the four main orientations: N-E-S-W. This kind of variation would reveal the impact of environmental factors as driving rain and solar radiation. Alternatively, the weather data can be analysed and the orientation with the biggest impact can be found (see Figure 7, where the worst orientation with regard to driving rain is SW-W). A calculation with the orientation with biggest impact of driving rain and/or solar radiation used as worst case and the opposite orientation as least worst case would often be enough.

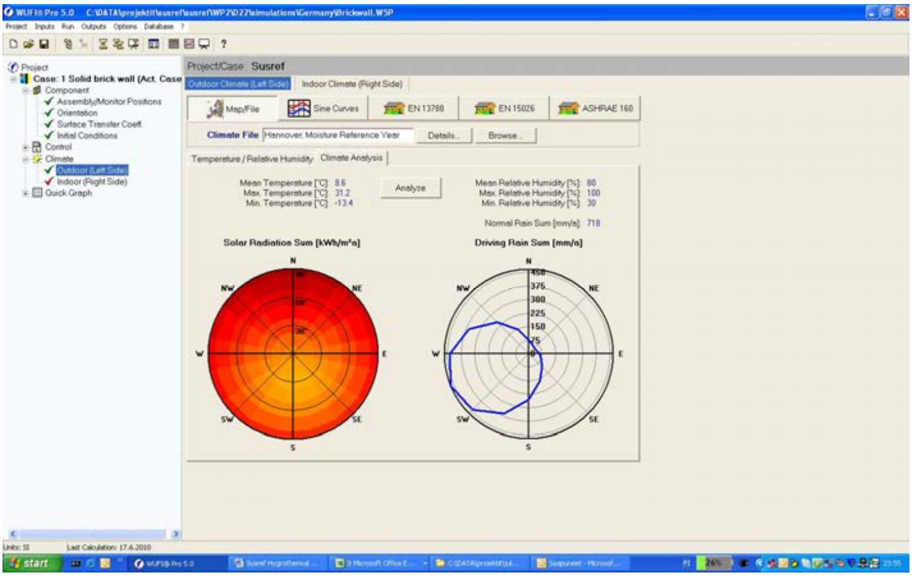


Figure 7. Analysis of weather data in Wufi: Amount of solar radiation and driving rain as a function of orientation in Hannover.

The simple and common way of calculating the driving rain load S_d, is given with Equation 1:

$$S_d = s \cdot (R_1 + R_2 \cdot v) \quad (1)$$

where s is free rain, v [m/s] is wind velocity in orthogonal direction to surface. R_1 and R_2 are coefficients, e.g. R_1 = 0 for vertical facades and R_2 = 0.2 for un-disturbed driving rain. If your software calculates the driving rain – combination of wind speed, wind direction and perception – make a sensitivity analysis of the impact of it. The worst case would be in the corners of a tall building ($R_2 \geq 0.2$) and the least worst case in the middle of a low building facade (R_2 = 0.07). One of the possibilities to model driving rain in WUFI is to use Equation 1.

Interior conditions

For numerical simulations of the external walls, the typical temperature and relative humidity or additional moisture of the interior climate ranges should be used.

In general, EN ISO 13788, Annex A (CEN 2001) gives moisture loads for use in calculation of surface temperatures to avoid risk of condensation. But this model is intended for steady-state assessment of interstitial condensation using the Glaser method. EN 15026 (CEN 2007) describes numerical assessment of transient moisture transfer. This standard describes classes for high and low occupancy office buildings or dwellings.

User preferences and habits vary, affecting the way the users interact with the building and its technical systems. For building simulations it is often supposed that the indoor temperature will be kept somewhere between 20 °C and 25 °C (EN 15026) or in a narrower band (ASHRAE Standard 160), but some users may prefer higher or lower temperature than this, either for comfort or for trying to save energy. The moisture productive activities vary from the user to another. The ventilation system and rates have a huge impact on the resulting indoor air temperature and especially moisture concentrations. Thus, relative humidity may vary considerably between different buildings and even in different rooms in a single dwelling.

As a first choice for the analysis, moisture loads according to EN 15026 as a function of outdoor climate are therefore recommended to be used. A screen dump from WUFI program in Figure 8 shows the variation of both indoor temperature and indoor relative humidity as a function of the outdoor climate and internal moisture load. Use both standard and high moisture load for parameter analysis according to EN 15026.

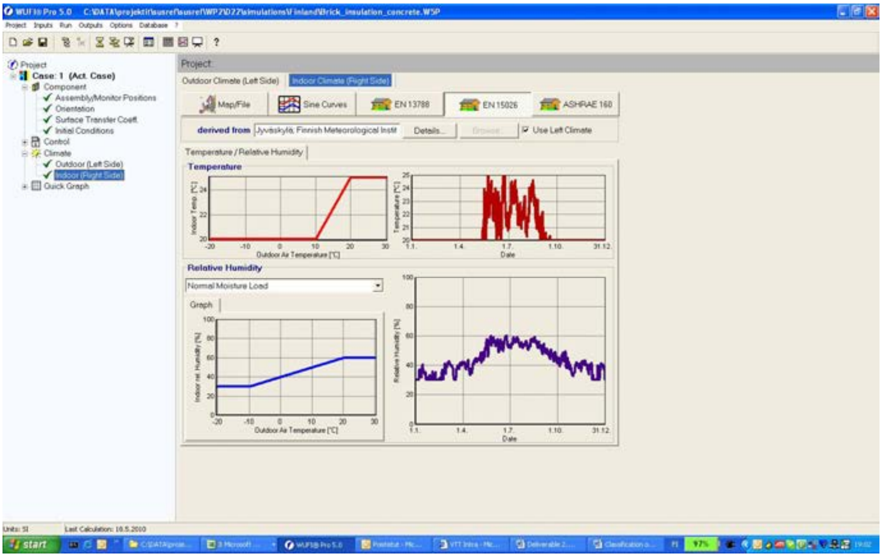


Figure 8. Definition of indoor climate as a function of outdoor climate according to EN15026. This figure illustrates well why EN 15026 is more realistic than the EN13788 as the indoor temperature in EN 15026 floats up to 25 degrees as a function of outdoor temperature during the warm periods and is not fixed at 20 as in EN13788, which would require mechanical cooling.

The indoor climate will be (unrealistic) fixed when applying above standards. Therefore, there is a possibility to apply the resulting interior climate from a whole building simulation (e.g. EnergyPlus) as an indoor climate for a building physical simulation of the walls: A kind of "indoor weather data file" can be created for any actual case, where the indoor boundary conditions are variables and a result of the outdoor conditions, the whole building design including HVAC systems and the performance of the building envelope. By using such a resulting indoor weather file, it is possible to apply e.g. the integrated effect of the solar radiation load and the thermal capacity of the whole building to a realistic temperature scale of the indoor air.

Calculation and parameter variation

After selecting the suitable calculation tool, description of the construction and definition of the boundary conditions, the next step is the performing of the dynamic simulations. This section describes shortly some of the main parameters and assumptions for the calculations. Standard numerical setup of the calculations (accuracy, convergence, control of time steps etc.) depends on the software to be used and will therefore not be discussed here. The recommendations in the manual and professional experience should be followed.

Simulation time period

The dynamic simulations of external walls should typically run for 3–5 years and maybe more for the very massive constructions. The simulation period needed is based on the assumption of achieving so called quasi steady state for the analysed construction: The seasonal changes should be the same from year to year. The fulfilment of this criterion can be found with e.g. making the first calculation to take 10 years. Figure 9 illustrates the quasi steady state. Results for the first quasi steady state year are used for analysis.

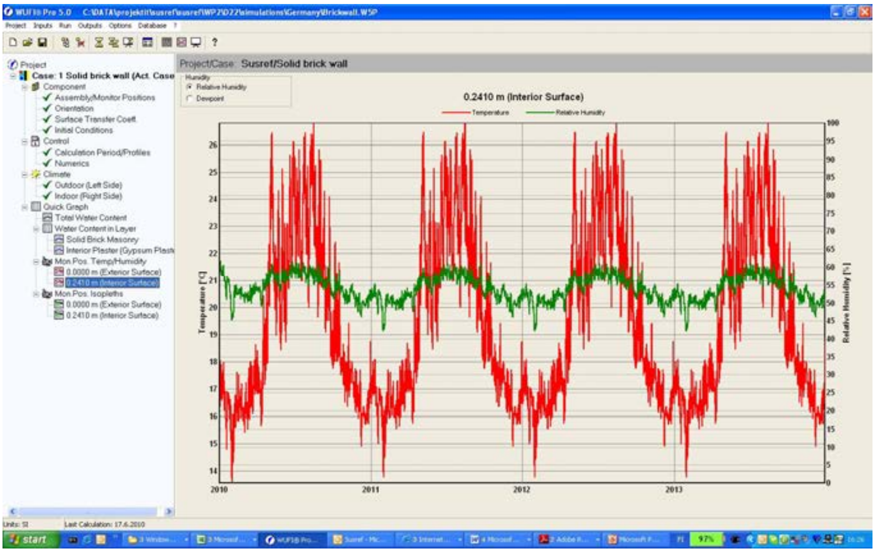


Figure 9. Illustration of the finding the quasi steady state for calculation. The simulation runs here for 4 years. In this case, the results for the 3. year fulfil the quasi-steady criterion and can be used for the further analysis.

During the calculation, the important variables at both interior and exterior wall surfaces and at any other critical locations/layers should be logged. These are listed in Table 2.

Table 2. Simulation output to be logged in every critical location.

Temperature	T [°C]	Hourly values for last year of simulation
Relative humidity	RH [%]	Hourly values for last year of simulation
Moisture content	w [kg/m^3]	Water content of a material layer or whole construction in the start of the last year of simulation and in the end of the year.

Hourly information on T and RH can be used for different types of hygrothermal analysis and post processing of some key figures (indoor thermal comfort, condensation risk, TOW, Mould index, etc). The yearly change in water content shows an overview on the potential for moisture accumulation. Basically, the moisture content should not be increasing.

Sensitivity analysis of parameters

Simulations should be run for a number of relevant parameters that may have an impact on the hygrothermal performance of the constructions. These are especially regarding:

- compass orientation
- outdoor climate type and loads (e.g.driving rain)
- any variation of surface properties relevant for the construction (e.g. colour for radiation, coatings for moisture diffusion resistance, etc)
- indoor moisture loads
- initial moisture content.

When assessing the influence of the initial moisture content (built-in moisture), the assumption of using the results for a quasi-steady solution is not relevant. For this parameter, the simulation period needed has to be estimated and to be run for e.g. 5 years in order to reveal the robustness of the construction for the built-in moisture, e.g. wetting of the materials on the building site.

The simulations should be performed at least for three different target U-values in order to illustrate the role of minor or larger energy saving potential of the refurbished construction on the hygrothermal performance – AND in order to reveal any trend in the hygrothermal performance as a function of energy savings, see Table 3. The final U-value of the refurbishment solution is a result of the whole assessment including the environmental aspects and therefore not necessary a fixed value from the beginning. However, for the preliminary analysis some target U-values need to be used. In this report, a method for defining three different intermediate target U-values for different climatic areas of Europe was shown, see Table 21 and text in that section for more details. The U-values of the original constructions need to be given or calculated for reference.

Table 3. The proposed parameters to be varied, and suggestions for the parameter values. The inclusion of the relevant parameters needs to be considered from case to case.

Parameter	**Suggested values for the parameters**			
Outdoor climate and type	Average year for the location		Extreme year (regarding moisture)	
U-values	Original	Energy saving target	Low (e.g. 70% of target)	High (e.g. 140% of target)
Orientation	North	East	South	West
Driving rain	Less exposed: $R_2 = 0.07$		Very exposed: $R_2 = 0.2$	
Indoor moisture load	Normal		High	
Initial moisture content	Normal: RH = 80%		High: e.g.RH = 100%	
Exterior surface diffusion resistance	None: $S_d = 0$ m		High: $S_d = 10$ m	
Interior surface diffusion resistance	None: $S_d = 0$ m		High: $S_d = 100$ m	
Colour of facade	Light: $\alpha = 0.4$		Dark: $\alpha = 0.88$	
Ventilation rate of ventilated cavities (if relevant)	Poor: $n = 1\ h^{-1}$	Standard: $n = 50\ h^{-1}$		Good: $n = 100\ h^{-1}$

Yet another group of parameters to be varied include:

- expected variation in the material data of the original construction materials
- choice and variation of materials (e.g. different types of insulation materials).

The sensitivity analysis of the expected variation in the material properties is recommended due to the great uncertainty around the material properties in the existing – and especially old – constructions. On the other hand, it is difficult to give any clear recommendations for a systematic analysis of this uncertainty as the material values have a very large variation range – depending on the material and the exposure conditions, too. Therefore, the need for sensitivity analysis has to be evaluated from the case to case. A study on the influence of uncertainty of input data on hygrothermal simulations shows that while probable variations in the indoor and outdoor climate have a great impact on the resulting hygrothermal behaviour of the construction, the influence of some material parameters like density, thermal conductivity and thermal capacity can often be neglected. But parameters related to the moisture storage capacity and the liquid moisture transport may have as big impact as the climate data. (Holm 2001)[47]

47 Holm, A. (2001). Drying of an AAC flat roof in different climates. Computational sensitivity analysis versus material property measurements. Paper to CIB-W40 Meeting, Wellington, New Zealand, April 2001

The variation and choice of materials to be used in the refurbishment solutions will be a function of the assessment process and should therefore be evaluated and varied throughout the process.

The alternative refurbishment solutions can be grouped roughly like in below list:

- internal insulation (parameters e.g.: insulation materials and thickness, vapour diffusion resistance)
- external insulation (parameters e.g.: insulation materials and thickness, with or without ventilation, with or without removing the original facade)
- insulation of the cavity (parameters e.g.: insulation materials)
- other ideas, e.g. protection of the facade with glass or using energy producing components.

The actual solution, including the composition of the construction, will set the requirements for the suitable materials. Therefore some materials are more suitable for solutions for internal insulation while others perform better as external insulation. The building physical simulation – which is the subject in these guidelines – will, however, not assess all durability aspects or practical usability of the materials in different solutions: The simulations concern purely hygrothermal physics and therefore common sense and knowledge on structural engineering must be used when evaluating the suitability of any material as a part of any refurbishment concept.

For the example case, the un-insulated brick wall, the initial simulations of the original construction showed a very high relative humidity (RH) of the interior surface (see Figure 10). This will most likely correspond to a high risk for mould growth on the interior surface. As a reason for the high RH is most likely the lacking thermal insulation in the combination of the unprotected brick wall exposed to the driving rain, which will make the wall too wet. This construction needs more insulation, and exterior insulation is normally the best solution when not dealing with listed buildings, etc. It is cost effective and results in no thermal bridging, see Figure 3. .

The construction illustrated in Figure 3 have a U-value of 0.2 W/(m^{2}K) with EPS as an insulation material with a thermal conductivity of 0.04 W/mK. In order to reach a U-value of 0.15 W/(m^{2}K), the homogeneous insulation thickness would be around 250 mm. The final insulation thickness depends, of course, on the used insulation material and the insulation system and the effect of thermal bridges of the system.

If there after the introductory sustainability assessment of the refurbishment concepts are several possible solutions for the refurbishment – internal or external or something else – all these alternatives should be simulated in order to find the building physically best solution. This may lead to laborious simulation if performed without running assessment. Therefore, the good experience in building physical assessment and a reasonable choice of parameters will lead to the best findings.

An example of the very limited set of parameters used for the performed simulations is seen in Table 4. The only parameter varied in these 4 simulations is the construction itself, resulting in different U-values. Nevertheless, this kind of presentation of the simulation cases gives a good overview if the studied cases.

Table 4. An example of the presentation of the simulated cases with the parameter information.

Parameter/Simulation case	**Level**	**Value**	**1**	**2**	**3**	**4**
Outdoor climate, type	standard	Hannover	x	x	x	x
	extreme					
U-value	original	U = 1.7 W/m^{2}K	x			
	U_high	U = 0.2 W/m^{2}K		x		
	U_medium	U = 0.15 W/m^{2}K			x	
	U_low	U = 0.1 W/m^{2}K				x
Orientation	north	north				
	east	east				
	south	south	x	x	x	x
	west	west				
Driving rain	less exposed	R2 = 0.07				
	very exposed	R2 = 0.2	x	x	x	x
Indoor moisture load	normal		x	x	x	x
	high					
Initial moisture content	normal	RH = 80%	x	x	x	x
	high	RH = 100%				
Exterior surface diffusion resistance	none	S_d = 0 m	x	x	x	x
	high	S_d = 10 m				
Interior surface diffusion resistance	none	S_d = 0 m				
	high	S_d = 100 m	x	x	x	x
Colour of facade	light	α = 0,4	x	x	x	x
	dark	α = 0,88				
Ventilation rate of ventilated cavities	poor	n = 1 h^{-1}				
	standard	n = 50 h^{-1}				
	good	n = 100 h^{-1}				

Analysis and assessment of the results

The purpose of performing a set of hygrothermal simulations with parameter variations is to create basis for presentation of the results in such way that a potential trend of solutions will be revealed. The result could be e.g. that the insulation thickness should not exceed a certain value with a specific insulation material or exterior finish or if a non-ventilated construction is used.

Temperature and relative humidity conditions

One of the basic outputs from the dynamic heat and moisture simulations are the hourly T and RH in a specific location of the construction. The number of these locations to be assessed depends strongly on the studied construction type. Figure 10 shows the temperature and relative humidity of the indoor surface of the original, non-insulated brick wall used as an example. This kind of result presentation illustrates easily, if there is a potential problem, like in this case: due to the non-insulated wall, the surface temperature of the wall in contact with indoor air varies strongly as a function of outdoor air. This combined with the relatively heavy load of driving rain (in this case R_2 = 0.2) – and no water protection of the facade –, which wets the construction from outside, the relative humidity of the interior surface is very high giving optimal conditions for mould growth (see Figure 11).

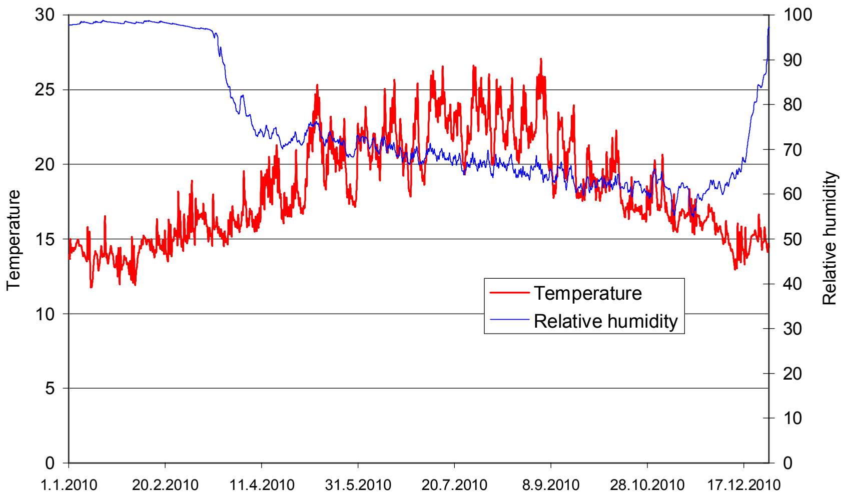


Figure 10. T and RH on the indoor surface of the massive brick wall facing south in Hannover.

These kinds of observations are good to be related to the reported problems in buildings with such walls when analysing any concrete case of refurbishment. The nature of the major problem or the sum of problems give guidelines for what kind of refurbishment solution may lead to a well-performing facade. The problem with the original construction may typically be one or several of these

- leakage of air (original flaws in the construction or cracks due to ageing)
- wetting from outside (capillary suction, no water protection, bad detailing)
- poor or no insulation (high heating energy use and cold interior surface, possibly leading to mould growth)
- wrong materials in wrong places (accumulating of moisture, sensitive materials).

These observations are good for the qualitative analysis of the performance.

In order to quantify the input to the assessment procedure, numerical data is needed as output from the hygrothermal calculations. There are 2 different methods: using a dynamic model for the post-processing or using some simple key figures. Both methods are presented here but the focus will be on the simple, engineering method.

Analysis with dynamic models

One of the possibilities for post-processing the simulated temperature and relative humidity data is to perform the numerical mould growth calculations and get e.g. the predicted mould growth risk for critical parts of the construction. Figure 11 shows the calculated mould index during a three year period for the internal surface of the original example construction. The mould index is calculated on T and RH given in Figure 10.

The assumptions for the mould growth calculation are that the material of interior surface is relatively sensitive to biological growth, i.e. wall paper. The results form the used VTT model for prediction of mould growth, which here is used with the latest new sensitivity classes, must be seen in relation to other solutions and not as absolute values. The most important information from the Figure 11 is, however, that the modelled mould growth is increasing from year to year. This makes the hygrothermal conditions of this original construction unacceptable.

The best way to use the predicted mould growth as an assessment tool is to compare different refurbishment solutions with each others: The solution with the lowest risk for the mould growth would most probably also have least other moisture related problems. When the example case is refurbished with the external insulation system as shown in Figure 3, the Mould index for the interior surface is 0 for all 3 insulation thicknesses. For other cases and construction solutions a difference in the predicted Mould index may help to find the best solution.

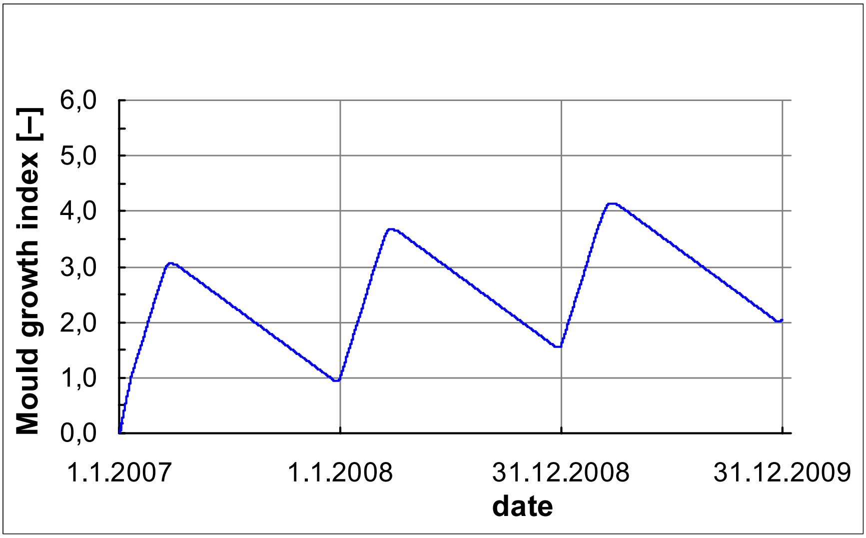


Figure 11. The mould growth index calculated from the data in Figure 10. The growth model is the modified VTT model and the growth index has been calculated for a sensitive class with the relatively strong decrease of the mould growth (0.5) outside the growth conditions.

Analysis with simple key values

Another approach for post-processing the simulated temperature and relative humidity data is to determine a set of simple key values from the T and RH and assess the different solutions with them. The following list shows the parameters that should be determined for the different combinations of parameter variations (Table 4). Summary of the recommended performance criteria for building physical assessment is found in table form in

Table **6**.

The graphical presentation of the results will often help to find any trends and the best solution.

1. U-value of the construction
2. Annual transmission heat loss based on t (Figure 23)
3. Temperature factor f_{Rsi}
4. Lowest indoor surface temperature, T_{min}
5. Amount of accumulated water in the construction, Δw, during a year
6. Running averages of temperature and relative humidity according to the criteria given in Table 23 and resulting number of hours exceeding the criteria or
7. TOW (time of wetness) according to the different criteria for different risks, as grouped together in Table 5 and eventually also
8. Thermal bridge effects (if relevant) for use in whole building simulations = an addition to the U-value.

Table 5. Calculation criteria for time of wetness (TOW) to be used in the hygrothermal assessment.

	TOW for different performance criteria		
	Frost	Mould, corrosion	Condensation, algae, decay
Temperature	< 0 °C	> 0 °C	> 0 °C
Relative humidity	> 95%	> 80%	> 95%

Time of wetness (TOW), i.e number of hours above/below given threshold values depending on the risk in focus, was chosen to be used in this project as a simple key value also for assessing the risk for mould growth because it is a relatively simple to understand and implement in calculation work. Note that different risks are assessed with different threshold values.

The different presented criteria for hygrothermal performance are typically determined by numerical HAM-simulations either in 1D or 2D. A very central issue in the simulation work is, however, the sensitivity analysis of any significant parameters. With such a sensitivity analysis, the expected range of any natural variation in material parameters and e.g. weather exposure and indoor loads can be found and can result in an expected risk.

Another approach is to make probabilistic analysis, where all input parameters can e.g. be varied randomly. The result will not be a numerical value of the risk but a probability function, which, however, will describe the risk more realistic.[48]

48 Pietrzyk, Krystyna (2010) Thermal Performance of a Building Envelope – A Probabilistic Approach. Journal of Building Physics Vol: 34 Issue: 1. ISSN: 1744-2591 Date: 07/2010 Pages: 77–96.

Table 6. Summary of the performance criteria for hygrothermal assessment that are recommended to be used in this project.

Criteria	**Description**	**Symbol**	**Unit**
Thermal performance	Transmission coefficient	U-value	W/(m^{2}K)
	Thermal bridge effect	f_{Rsi}	-
Moisture performance	Annual moisture accumulation	Δw	kg/year
	Time of wetness (TOW)		
	Risk for frost damage T < 0 °C, RH > 95%	TOW	h
	Risk for mould, corrosion T > 0 °C, RH > 80%	TOW	h
	Risk for condensation, algae, decay T > 0 °C, RH > 95%	TOW	h
Indoor climate	Lowest indoor surface temperature	T_{si}	°C

Therefore, setting any numerical criteria for performance is difficult and risky, but a must for a proper assessment.

A central challenge in the assessment work is hereafter to evaluate these very different criteria as one number in order to find the best refurbishment solutions: The purpose is, nevertheless, to

- minimise all risks:
  - no moisture accumulation, the better drying potential the better performance
  - TOW as low as possible for all the considered risks
  - T_{si} as high as possible in order to ensure excellent thermal indoor environment and good indoor air quality (e.g. no risk of mould growth due to the low surface temperatures)
- and maximise the benefits:
  - as low U-values as possible in order to save heating energy
  - no thermal bridges in order to save heating energy and improve the indoor environment.

Application of measurements

If possible, the numerical analysis of the refurbishment solutions should be supplied by selected experimental tests in a laboratory or in the field, e.g. pilot case. This is most relevant for any innovative solutions where no long-term experience is available. The implementation of new (insulation) materials or use of materials and components in a non-traditional way are examples on cases, where results from laboratory or field measurements are essential for the proper assessment of the performance.

It is essential to analyse and identify for all the considered refurbishment solutions. Among questions to be answered:

- When (new) materials are used in a new way?
- Where are the potential problems most likely to appear?
- How uncertain are the performed simulations?
    - e.g. uncertainty about material values, weather data.

No result form an even advanced numerical simulation is better than the input data given for the model. Therefore, to answer the above considerations, expert knowledge and experience is needed.

Figure 12 shows an example on a refurbishment solution, where monitoring points are marked for the typical locations, where potential problems most likely will appear:

1. On the exterior side, which is colder now
2. In the interface between old and new construction. The performance depends for example on the vapour permeability of the new interior insulation and sheating.
3. The conditions on the interior surface are interesting for documentation of the targeted improvement of the indoor air and environment quality.

Simultaneous measurement of temperature and relative humidity in the critical locations can be used to evaluate the hygrothermal performance in the same way as for the simulations (see the previous section for the analysis).

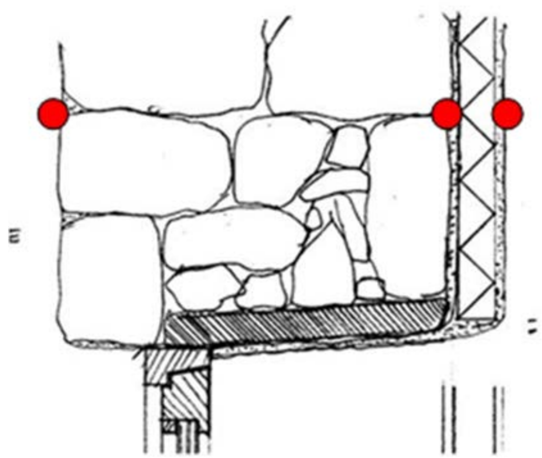


Figure 12. An example for the monitoring points for measurements of a refurbishment solution: Internal insulation of the solid wall. In order to prove the hygrothermal performance, temperature and relative humidity should be logged at least on the given locations.

The measurement of the refurbished construction should be supplied with some measurements for the original construction, too, for reference and especially for the documentation of the improved performance.

The conditions and the duration of the measurements depend strongly on the construction type and the geographical location and the typical exposure of the construction. A minimum measurement period is one year, including both typical summer and typical winter conditions. Accelerated tests in a laboratory will, of course, give qualified results in a shorter time.

Appendix E: An example of the template for documentation of the construction and the results

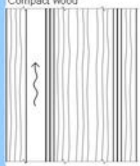
Description of the construction

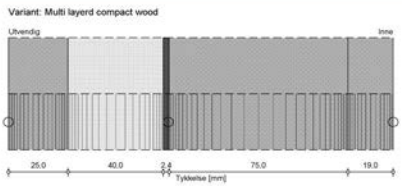
Location

Region	2. Dbf-cold, without dry season and with warm summer
Weather station	Oslo
Biggest impact from	S

Original construction

Wall type description	Multi layered compact wood
Short name	Compact wood
Picture & Model	





Typical problems: No insulation at all. High heat loss. etc.

Materials & Layers

Layer nr (from exterior)	Material	Thickness [m]	Thermal conductivity [W/mK]	Thermal resistance [(m*K)/W]	Bulk density [kg/ m³]	Porosity [m³/m³]	Spec. heat capacity [J/(kgK)]	Water vapour diffusion resistance [-]	Reference Water Content at RH=80% [kg/m³]
1	wooden cladding	0,025	0,12	0,208					
2	air cavity	0,04		0,090					
3	2x impr. building paper	0,002		0,080					
4	wood (standing plank)	0,075	1,20E-01	0,625					
5	building paper	0,001		0,050					
6	wood panel	0,019	1,20E-01	0,158					
7			1,00E+07	0,000					
8			1,00E+07	0,000					
9			1,00E+07	0,000					
10			1,00E+07	0,000					
surface resistance				0,17					

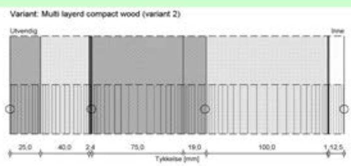
U-value (calculated here, if homogeneos layers) 0,72 W/(m²K)

U-value (determined with 2D calculation or method for inhomogeneous lay or W/(m²K)

Refurbished construction

Picture & Model

add a sketch of the refurbisment solution



Motivation for the refurbisment solution: Need more insulation. For listed buildings interior insulation is in many cases the only posible solution, even though exterior insulation is the best solution in regard to moistu

Materials & layers

Layer nr	Material	Thickness [m]	Thermal conductivity [W/mK]	Thermal resistance [(m^2K)/W]	Bulk density [kg/ m³]	Porosity [m³/m³]	Spec. heat capacity [J/(kgK)]	Water vapour diffusion resistance [-]	Reference Water Content at RH=80% [kg/m³]
1	wooden cladding	0,025	0,12	0,208	390	0,75	1600	108	58,33
2	air cavity	0,04		0,090	1,3	0,999	1000	0,38	
3	2x impr. building paper	0,002		0,080	909	0,001	1500	350	
4	wood (standing plank)	0,075	1,20E-01	0,625	390	0,75	1600	108	
5	building paper	0,001		0,050				0,9	
6	wood panel	0,019	1,20E-01	0,158	390	0,75	1600	108	
7	mineral wool	0,1	0,038	2,632	60	0,95	850	1,3	
8	PE-foil	0,00015		0,050	130	0,001	2200	70000	
9	Gypsum board	0,012		0,060	850	0,65	850	8,3	
10			1,00E+07	0,000					
surface resistance				0,17					

U-value (calculated here, if homogeneos layers) 0,24 W/(m²K)

U-value (determined with 2D calculation or method for inhomogeneous lay or W/(m²K)

Insulation thickness / material variations:

Material	Thickness [m]	Thermal conductivity [W/mK]	U-value W/(m^2K)
Mineral wool	0,1	0,037	0,24
	0,2	0,037	0,15

Cases and parameters

On the "Results" sheet, all the information about the parameter variations for the different cases should be collected.

Case No	Description	Calculation parameters (from "Parameters") Here give the numerical values given in "Parameters" sheet. **The parameters in bold** have in most cases the priority and the others are optional.								
		Orientation	Outdoor climate, type	**Driving rain**	**Indoor moisture load**	**Initial moisture content**	Exterior surface Sd	Interior surface Sd	Colour of facade	Ventilation of cavities
	Compact wood									
1	**Original**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor
2	**U=0,24**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor
3	**U=0,15**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor
4	**U=0,24**	north	Oslo, MDRY	R2=0,07	high	80 %	none	none	alfa=0,4	poor
5	**U=0,24**	north	Oslo, MDRY	R2=0,2	normal	80 %	none	none	alfa=0,4	poor
6	**U=0,24**	south	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor
7	**U=0,24**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	standard
8	**U=0,24 - Sd-wind barrier = lower**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor
9	**U=0,24 - Sd-wind barrier = higher**	north	Oslo, MDRY	R2=0,07	normal	80 %	none	none	alfa=0,4	poor

Simulation result charts

Selected temperature (T) and relative humidity (RH) charts to show some typical behavior of the different solutions should be added on the "Result charts" sheet. Some examples on such charts are given below.

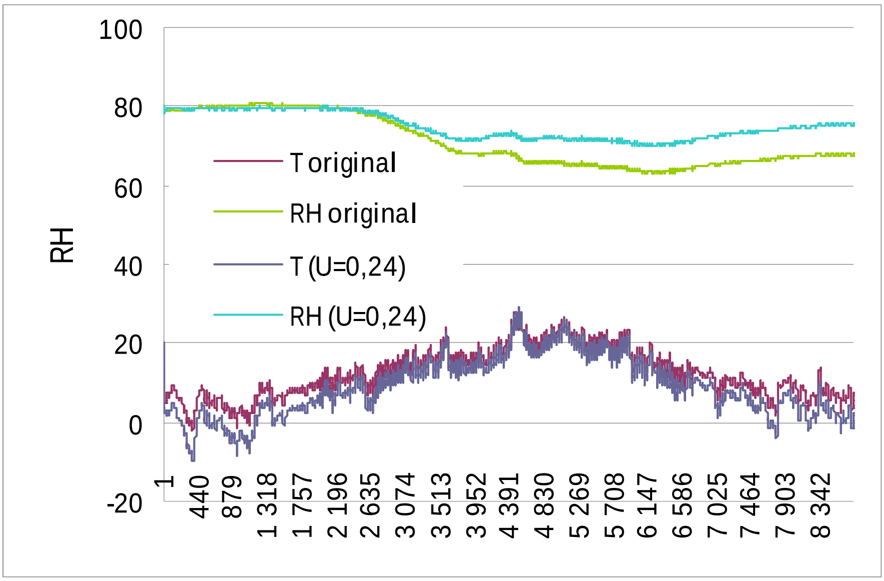


Figure 1. The figure shows the temperature (T) and relative humidity (RH) during one year at the inner side of the wind breaking barrier in a multilayerd compact wood wall with a U-value 0.72 W/m^{2}K (original) and a refurbished wall with U-value 0.15 W/m^{2}K.

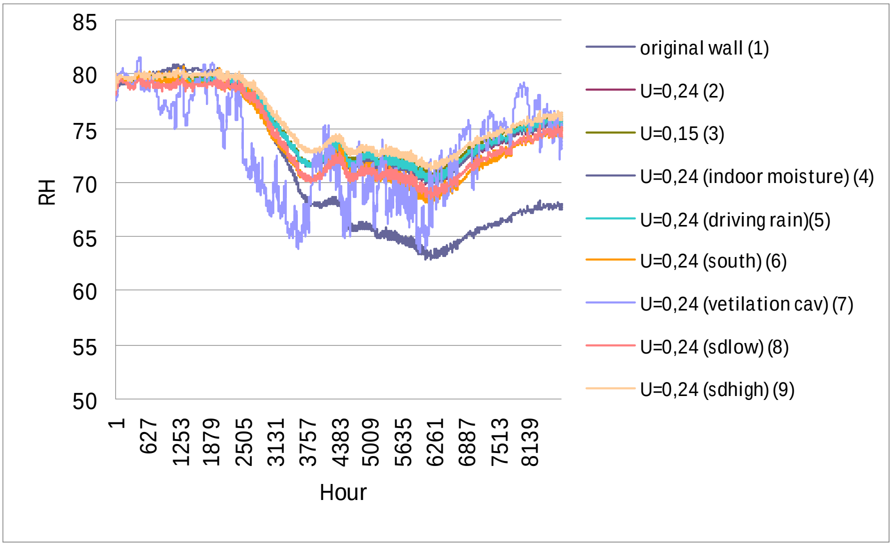


Figure 2. The figure shows the relative humidity at the inner side of the wind breaking barrier in a multilayerd compact wood wall for the original wall with U-value 0.72 W/m^{2}K (1) and refurbished walls with U value 0.24 W/m^{2}K (2) and 0.15 W/m^{2}K (3). The figure also shows the effect different simulation parameters such as high indoor moisture load (4), driving rain (5), south side of the building (6), ventilated cavity (7) low (8) and hig (9) sd value on the wapor barrier have on the relative humidity.

Analysis: Simple key values (Tables and charts)

On the "Results" sheet, all the performance key values for the different calculated cases should be collected. An example of the presentation template is given below. Also an example on a graphical presentation of the key values is given.

Description	Thermal performace U-value from "Construction" sheet			Indoor climate
	U-value	Annual Heat loss	fRsi	T_min_si
Compact wood	W/(m2K)	kWh/m2	-	°C
Original	0,72	81,5	0,91	16,3
U=0,24	0,24	27,2	0,97	18,9
U=0,15	0,15	17,0	0,98	19,2
U=0,24	0,24	27,2	0,97	18,9
U=0,24	0,24	27,2	0,97	18,9
U=0,24	0,24	27,2	0,97	18,9
U=0,24	0,24	27,2	0,97	18,9
U=0,24 - Sd-wind barrier = lower	0,24	27,2	0,97	18,9
U=0,24 - Sd-wind barrier = higher	0,24	27,2	0,97	18,9

Description	Moisture performace									
	Moisture accumulation	Frost T<0C, RH>95	Mould, corrosion T>0, RH>80				Condensation, algae, decay T>0, RH>95			
	Δw	TOW_frost	TOW_se(rh>80)	TOW_cr1(rh>80)	TOW_cr2(rh>80)	TOW_si(rh>80)	TOW_se(rh>95)	TOW_cr1(rh>95)	TOW_cr2(rh>95)	OW_si(rh>9
Compact wood	kg/year	h	h	h	h	h	h	h	h	h
Original	-1,919	0	2277	1305		0	35	0		0
U=0,24	-0,718	37	2433	3	1243	0	320	0	0	0
U=0,15	-0,588	75	2442	130	5785	0	439	0	43	0
U=0,24	-0,688	37	2433	3	1344	0	320	0	0	0
U=0,24	-0,694	44	2526	5	1244	0	570	0	0	0
U=0,24	-0,800	34	2425	53	1349	0	670	0	0	0
U=0,24	-0,815	46	2449	367	1221	0	364	0	0	0
U=0,24 - Sd-wind barrier = lower	-0,779	37	2433	0	1239	0	320	0	0	0
U=0,24 - Sd-wind barrier = higher	-0,647	37	2431	465	1241	0	320	0	0	0

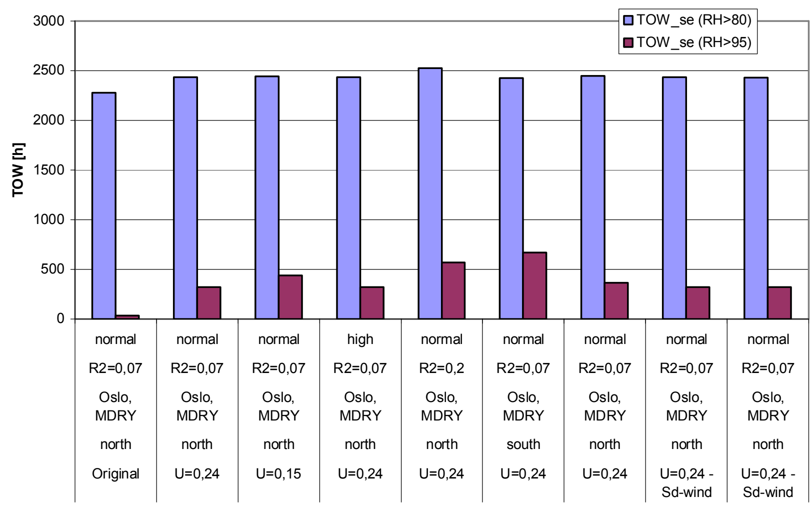


Figure 3. Time of wetness (TOW) for the exterior surface. TOW criteria for mould etc (RH > 80) and condensation etc (RH > 95).

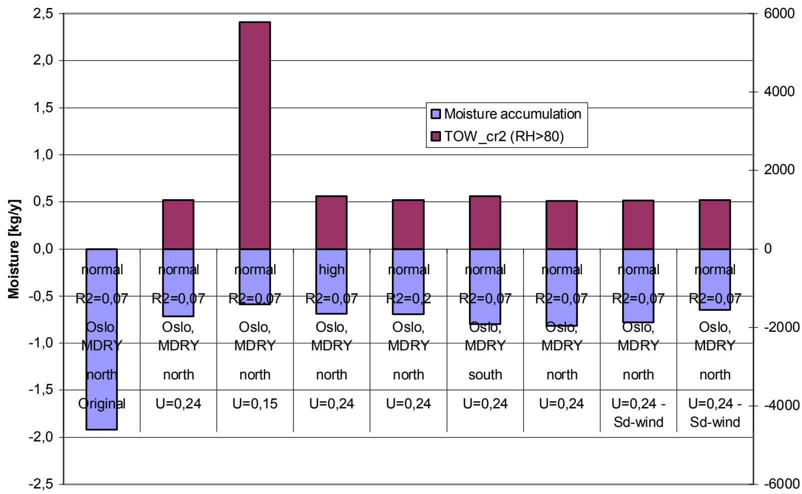


Figure 4. Moisture accumulation potential and time of wetness (TOW) behind the wind barrier. TOW criteria for mould etc (RH > 80).

In addition to the tables and graphs, a short conclusion of the assessment results should be given. For the example case:

Conclusion

It can be concluded on the basis of the relatively limited set of parameters that the refurbished construction – with the interior insulation – will have a good hygrothermal performance if the water vapour resistance of the wind barrier is kept low. A single analysis of the insulation thickness show increasing risk for mould related problems if the U-value is further decreased from 0.24 W/m^{2}K to 0.15 W/m^{2}K. Nevertheless, the drying capacity of the construction is not affected by the increasing insulation thickness.

Series title and number

VTT Technology 30

Title	**Sustainable refurbishment of exterior walls and building facades** Final report, part A
Author(s)	Tarja Häkkinen (ed.)
Abstract	This report is the final report of Sustainable refurbishment of building facades and exterior walls (SUSREF). SUSREF project was a collaborative (small/medium size) research project within the 7th Framework Programme of the Commission and it was financed under the theme Environment (including climate change) (Grant agreement no. 226858). The project started in October 1st 2009 and ended in April 30th 2012. The project included 11 partners from five countries. The coordinator of the project was Tarja Häkkinen, VTT. SUSREF developed sustainable concepts and technologies for the refurbishment of building facades and external walls. This report together with SUSREF Final report Part B and SUSREF Final Report Part C introduce the main results of the project. Part A focuses on methodological issues. The descriptions of the concepts and the assessment results of the developed concepts are presented in SUSREF Final report part B (generic concepts) and SUSREF Final report Part C (SME concepts).
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