

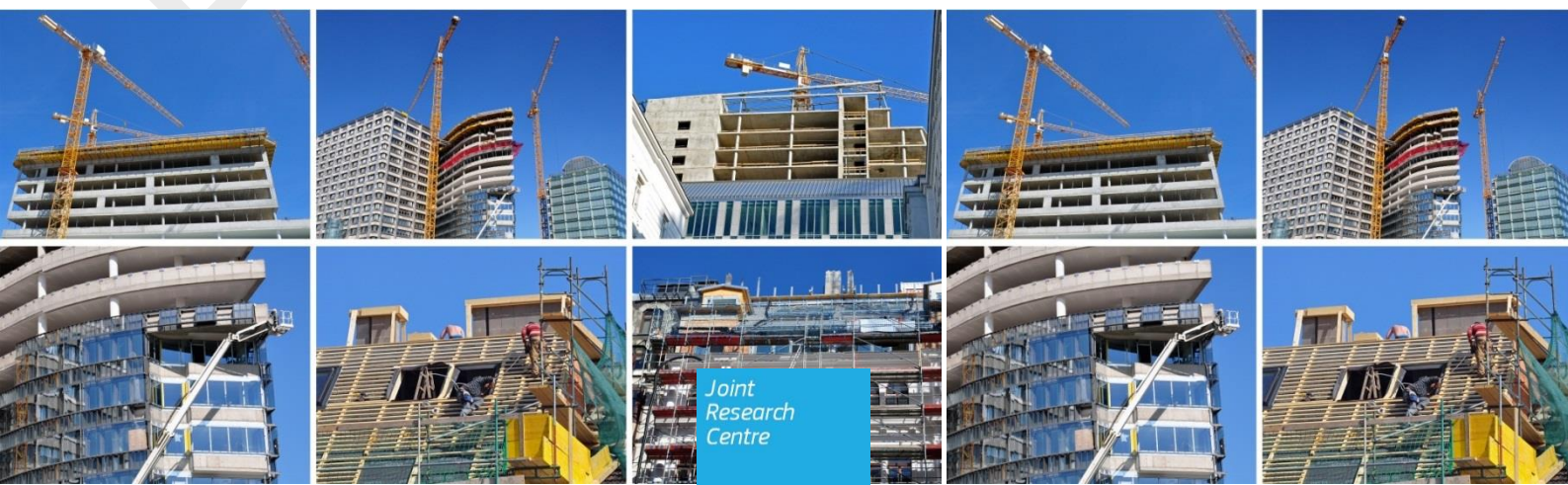
## JRC TECHNICAL REPORTS

# Identifying indicators for the life cycle environmental performance, quality and value of EU office and residential buildings

*(Draft) Working Paper 2*

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## 1. Introduction

The European Commission's 2014 Communication on Resource Efficiency Opportunities in the Building Sector identified the need for a common EU approach to the assessment of the environmental performance of buildings. A study to develop this approach was initiated in 2015 by DG ENV and DG GROW, with the technical support of DG JRC-IPTS.

The output from the first stage in this study during 2015 was a first Working Paper identifying 'macro-objectives' for the life cycle environmental performance of buildings. This second Working Paper reports on the interim findings of the second stage of the study, in which performance indicators at building level will be identified.

It provides an analysis of a range of evidence for action at building level that has contributed towards six of the macro-objectives:

- Public sector initiatives at national and regional level, including building permitting and planning requirements;
- Building practitioners: Feedback from field studies of building projects where higher environmental performance has been sought;
- Assessment and reporting schemes: The operational experience from running and using major multi-criteria certification schemes and investor reporting tools currently being used across Europe;
- Technical studies: The findings from studies that synthesise experience and expertise from the building sector in one or several member states in order to propose or refine performance measurement tools, metrics and guidance;
- Standards and harmonisation initiatives: The findings from projects to support greater harmonisation and uptake of performance measurement and reporting tools;
- Collaborative EU projects: The findings from collaborative EU projects that have brought together partners to share knowledge and experience related to performance improvement.

The evidence brought together in this working paper, has been used to identify performance indicators under each of the macro-objectives. An initial identification of preferred options for indicators has been made in order to stimulate discussion with stakeholders.

### 1.1 The final set of six macro-objectives that were identified

In Working Paper 1, two types of macro-objectives were identified – those relating to *'life cycle environmental performance'* and those relating to *'quality, performance and value'*. Six of these macro-objectives have been taken forward in order to identify related performance indicators. All six of these macro-objectives will focus on action at the building level:

*'Life cycle environmental performance' macro-objectives for buildings*

- **1. Greenhouse gas emissions from building life cycle energy use:** Minimise the total GHG emissions along a buildings lifecycle, with a focus on building operational energy use emissions and embodied emissions.
- **2. Resource efficient material life cycles:** Optimise building design, engineering and form in order to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts.
- **3. Efficient use of water resources:** Make efficient use of water resources, particularly in areas of identified long-term or projected water stress.

*'Quality, performance and value' macro-objectives for buildings*

- **4a. Healthy and comfortable spaces:** Design, construction and renovation of buildings that protect human health by minimising the potential for occupier and worker exposure to health risks.
- **5. Resilience to climate change:** The futureproofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort.
- **6. Optimised life cycle cost and value:** Optimisation of the life cycle cost and value of buildings, inclusive of acquisition, operation, maintenance, disposal and end of life.

A further set of up to ten macro-objectives were identified that may potentially be considered for the identification of performance indicators in the future.

## 1.2 The aims and objectives of work packages B and C

Having identified the macro-objectives during 2015 (work package A), the aim of work programme during 2016 is to identify, propose and consult on indicators that can be used at project level to measure the performance of buildings against the six macro-objectives identified to be taken forward at a building level (work packages B and C). The relationship between the Work Packages is illustrated in Figure 1.1.

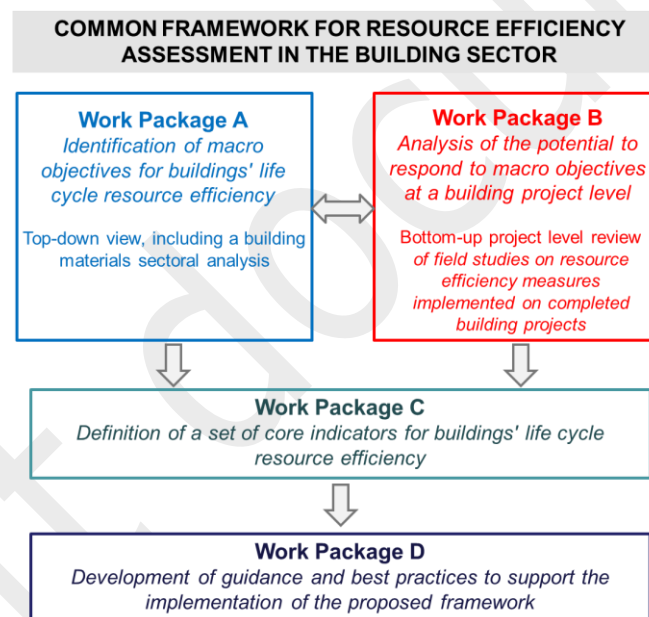


Figure 1.1. Overview of the Work Packages that make up the common framework study

The aim of work package B of the study is to understand the scope and potential in the short to medium term to address the macro-objectives at a building project level, taking into account different building uses, forms, and possible geographical and cultural influences. This 'bottom up' analysis is intended to ensure that there is a practical link between the indicators and the 'top down' perspective of the macro-objectives - a key aspect that was highlighted in discussions within the steering group.

## 1.3 Identification of suitable performance indicators

### 1.3.1 Definition of a 'performance indicator'

The indicators selected are intended to be performance based and quantifiable, so as to support as far as possible performance comparisons. A working definition of an indicator is provided below:

*'A specific and measurable aspect of a building's performance that can be used to support performance comparisons, benchmarking and target setting. Performance improvements measured by an indicator shall contribute to achievement, overall or in part, of the macro-objective that the indicator is associated with.'*

An indicator could be a metric for directly measuring performance of a variable, or where this is not possible, a proxy based on scientific evidence. Supporting indicators could also be identified. These would measure aspects of performance that evidence shows can in turn have a strong influence on overall performance against a headline, aggregated indicator for the whole building.

### 1.3.2 Defining what makes a suitable indicator

The 2014 Communication on Resource Efficiency Opportunities in the Building Sector - COM(2014)445<sup>1</sup>, which sets the scene for this study, described a number of anticipated sectoral benefits from having an EU core set of indicators, as well as potential advantages to building sector professionals. These were summarised in Chapter 1 of Working Paper 1.

It is considered important that any indicator identified supports the realisation of the Commission's anticipated benefits and advantages. It is therefore proposed to establish a set of criteria that define suitable indicators. This will allow for all the indicator options that emerge to be screened against a consistent set of criteria. The proposed evaluation criteria are listed in the box below. It is not, however, intended that these act as pass or fail criteria, instead that they serve to inform discussion on selection of the preferred indicator set.

The full set of indicators identified by the study will be recorded and made available to stakeholders. From this long list, it is the intention that a short list of preferred options is then identified for each MO. The evaluation criteria will be used to assist this process.

#### *Box 1.1 Criteria to inform identification of suitable performance indicators*

Overall suitability: The chosen metric is suitable for measuring the specified performance aspect of a building (*either directly, or indirectly as a proxy*);

Broadly applicable: They should be applicable to the identified scope of building uses/typologies, although there could be variations tailored to specific uses *e.g. residential valuation*;

From design to actual performance: The indicator can be used as a monitoring tool to track performance from the design stage, using modelled or estimated data, to the use stage, at which point design and actual performance will be possible to compare, right through to the end of life stage.

Accessible and understandable: They should be based on simple, accessible and easy to understand concepts that can be communicated to building professionals, both on the client side (*investors and project promoters, property market agent*) and on the design and contracting side (*e.g. main contractor, architect, structural engineer, quantity surveyor*). Only basic training should be required to make use

<sup>1</sup> COM(2014)445 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions on resource efficient opportunities in the building sector

of the indicator set.

Readily available and accepted: It should be possible to calculate/report on them using readily available, scientifically robust and accepted data, methods, tools and units of measurement/appraisal. Where possible, they should therefore use familiar and widely adopted normative references. (= they could still be 'new' in the sense that they may be familiar to professionals but not currently be used by some/all existing certification schemes).

Comparable: They should support, as a minimum, comparisons/appraisals of functionally equivalent building designs at a project level by:

- i) clients/design teams *and*
- ii) between buildings in the immediate local property market *or* in local property portfolios.

Comparability could be broadened depending on the indicator and the factors to consider e.g. water use (between stressed areas in a region), climate change resilience (within a region or climate zone).

Easily verifiable: Performance against each indicator shall be possible to easily and cost effectively verify in terms of documentation, data collection, project processes, test methods and the availability of accredited verification (*if required*).

Public sector policy friendly: They should potentially be useable by national, regional or local public authorities in the setting of planning and building control requirements, as well as in the procurement of public buildings.

Accounts for trade-offs and benefits: If significant potential trade-offs or benefits in performance between macro-objectives would not be captured by the calculation method specified for the indicator, then they should be addressed by links between MOs/indicators. If a significant potential trade-off cannot be addressed by linking to another MO then it would need to be reconsidered whether the indicator is suitable.

Three additional technical rules were established in Working Paper 1. These were identified from evidence as important aspects to take into account when measuring resource efficiency at building level:

- Unit of consumption: The functional unit shall reflect as far as possible the unit of consumption for the building *e.g. household (homes), workstation or employee (offices), pupil or class (school)*;
- Building form: Where possible, a performance comparison should be made between options for the building form in order to benchmark resource use intensity *e.g. factors such as form, density and height may influence the energy performance and the construction materials used.*
- Design parameters: For building structures, performance comparisons of material options shall be related to the design lifespan and shall additionally take into account fundamental engineering design parameters and safety factors, some of which will be specific to the location and form of the building *e.g. wind loads, earthquake resistance*;

These rules will form a reference point during the identification and discussion of indicator options.



## 2. Description of the methodology

### 2.1 Scope and definition

#### 2.1.1 Building types and projects

Following feedback received during the stakeholder consultation in 2015, it was decided to narrow the scope of the study to focus on residential and office buildings. These were chosen because they represent the majority (86%) of the total floor area of the EU building stock. Of this total, residential property represents by far the majority of the total floor area of the EU building stock (75%). For each of these uses, the execution of new-build and renovation projects will be considered during Work Packages B/C.

#### 2.1.2 Building project stages

In order to ensure that the findings from the study are linked to project execution, typical building project stages will be referred to throughout. Box 2.1 identifies a typical ordering these stages, with reference to the RIBA (Royal Institute of British Architects) Plan of Work (2013) <sup>2</sup>.

It is considered important to relate any findings to these stages in order to ensure there is a focus on the practical relevance of the indicators. In particular, this will help to identify at which stage in a project indicators may be more relevant, and involving which specific actors.

*Box 2.1 Scope of building project stages to be considered*

##### 1. Strategic definition and brief

*Includes:* analysis of existing situation, design brief, performance objectives, feasibility study, master-planning, outline development appraisal

*Key phases:* Existing building survey (for renovations)

##### 2. Concept design

*Includes:* concept, design development, preliminary technical studies and cost estimation

*Key phases:* design team appointment

##### 3. Developed and technical design

*Includes:* technical drawings, construction details, technical studies, building/technical specifications, bill of quantities, cost estimation, employer's requirements, tendering procedure/bidding phase,

*Key phases:* planning and building control permitting, bidding phase (including evaluation/commissioning), lead contractor appointment, environmental certifications

##### 4. Construction

*Includes:* demolition/site preparation works (may precede this stage), contract performance monitoring, as-built documentation, handover strategy

*Key phases:* Commissioning, quality testing/inspection

##### 5. Handover and close-out

*Includes:* (preliminary and final) delivery, defects period, post-completion verification of environmental certifications

*Key phases:* Commissioning, quality testing/inspection, building manual/training

<sup>2</sup> RIBA, *Plan of work 2013*, <https://www.ribaplanofwork.com/>

6. In-use

*Includes:* Occupation, operation, maintenance, repair, refurbishment

*Key phases:* Post occupancy evaluation, performance monitoring, building life cycle management plan

7. Refurbishment

*Includes:* See stages 1-5 (according to the scale of the works)

8. End-of-life

*Includes:* tendering procedure/bidding phase, pre-demolition inventory check

*Key phases:* Building disassembly, component and material reuse/recycling

### 2.1.3 Building life cycle stages

In order to ensure that the findings from the study are related to the life cycle of a building, the stages defined by CEN/TC 350 will be referred to throughout.

Figure 2.1 provides an overview of these stages. It is considered important to relate any findings to these stages because this will help to identify at which stage in a project indicators may be more relevant.

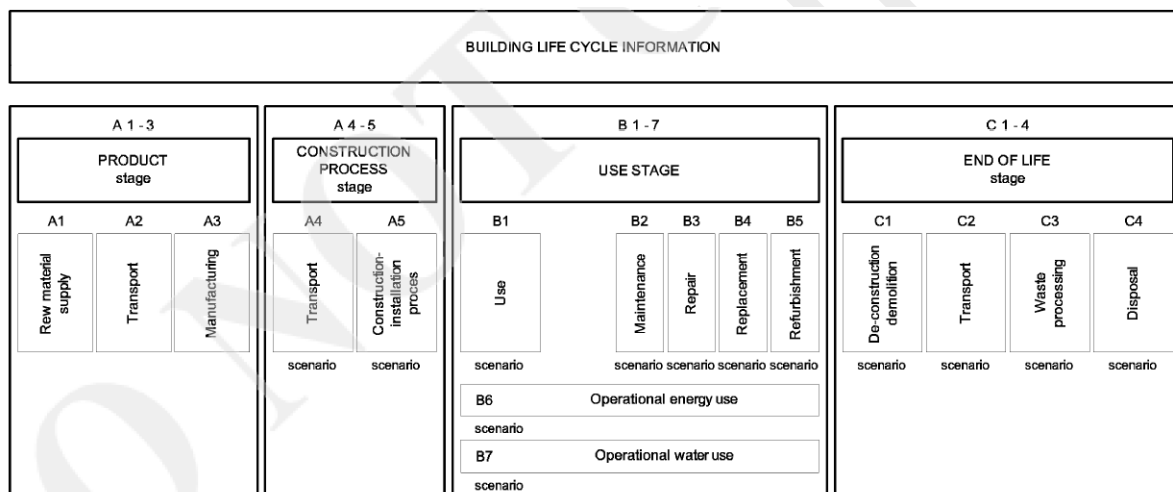


Figure 2.1 Scope of building life cycle stages to be considered

Source: CEN (2011)

## 2.2 The different types of evidence to be used

Options for the indicators have been identified based on a multi-layered evidence gathering exercise that is intended to be as comprehensive as possible for each macro-objective. This combines evidence gathered from:

- 'Field studies' (primary evidence)
  - Professional experience at project level of setting performance requirements and using indicators.
  - Technical research at building level to identify methods for measuring/monitoring performance.
- 'Cross-check' (primary and secondary evidence)
  - Public sector initiatives at national and regional level, including building permitting and planning requirements.

- Assessment and reporting schemes: The operational experience from running and using major multi-criteria certification schemes and investor reporting tools currently being used across Europe.
- Technical studies: The synthesis of experience and expertise from the building sector in one or several member states in order to propose or refine performance measurement tools, metrics and guidance.
- Standards and harmonisation initiatives: Projects to support greater harmonisation and uptake of performance measurement and reporting tools.
- Collaborative EU projects: The shared experience and outcomes from the sharing of share knowledge and experience related to performance improvement.

Evidence gathered from the detailed analysis of field studies of performance improvements at building and project level supports the identification of lessons from practical implementation. The information gathered from the field studies is supplemented by a range of 'cross-check' evidence that is specific to each macro-objective. This will ensure that the findings from the field studies are analysed within the broader professional, regulatory and technical context.

For each macro-objective, the comprehensiveness of the evidence base will be further ensured by, as far as possible, careful gathering of evidence to reflect the scope of the building types, geography and professional context – as summarised in Box 2.1.

*Box 2.2 Scope and factors to address in the selection of field studies and cross-check evidence*

1. Building-related factors

- *Completed projects with implemented improvements*
- *Building typology*
- *Building form*
- *Building age*
- *Market segment*

2. Geographical factors (*if directly relevant to the macro-objective*)

- *Climate zones*
- *Construction cultures*

3. Market factors (*relevant in particular to B6*)

- *The project promotor* (e.g. investment fund, speculative builder, affordable housing provider)
- *The form of contracting* could have sufficient influence on the division of financial costs, risks and benefits (e.g. Design, Build and Operate)

4. Professional and regulatory context (*cross-cutting*)

- *Building permitting in Member States*
- *Field studies carried out by collaborative EU projects*
- *Private or public sector buildings and portfolios*
- *Assessment according to specific criteria or indicators in a building scheme/reporting tool*

## 2.3 Identification and evaluation of options for indicators

Based on the evidence gathered, options will be identified for indicators under each macro-objective. The options will be screened with reference to the evaluation criteria laid down in Section 1.3.2.

These criteria have been developed further into an evaluation tool, with reference to the European Commission's RACER methodology, as recommended under Impact Assessment guidelines<sup>3</sup>. Figure 2.2 sets out the modified evaluation methodology, which divides the original criteria into sub-criteria, so as to support a quantitative scoring if deemed necessary. An example indicator selected from a multi-criteria assessment scheme is used to illustrate the potential scoring.

Figure 2.2 Modified RACER evaluation methodology for identification of suitable performance indicators

Example indicator

<i>Indicator</i>	<b>Energy Performance Ratio</b>
<i>Unit of measurement</i>	weighted contribution of <ul style="list-style-type: none"> <li>- MJ/m<sup>2</sup> (25%),</li> <li>- kWh/m<sup>2</sup> (41%)</li> <li>- kg CO<sub>2</sub> eq/m<sup>2</sup> (34%)</li> </ul>
<i>Source</i>	BREEAM UK non-residential 2014

Indicative evaluation of indicator 'Energy Performance Ratio' using RACER criteria

1. Relevance					
1.1 Broadly applicable to housing and office buildings	Data derived from National Calculation Methodologies for both typologies.	0	1	2	3
1.2 Can measure and track performance from design through to use and end of life stages	Sub-metered data for regulated energy end-uses would be required to make an accurate comparison	0	1	2	3
1.3 Useable by building control	kWh and sometimes CO <sub>2</sub> are regulated by building control.	0	1	2	3
1.4 Useable for planning	Planners may be less familiar at building level, but there are precedents	0	1	2	3
1.5 Useable for public procurement	Design teams and contractors responding to ITTs will be familiar with the metrics	0	1	2	3
2. Accepted					
2.1 Accessible and easy to understand for demand side	Understandable only when benchmarked or presented in the context of an EPC or operating costs	0	1	2	3
2.2 Accessible and easy to understand for supply side	Increasing familiarity with all three metrics, including kg CO <sub>2</sub> eq	0	1	2	3
3. Credible					
3.1 Is suitable for measuring the specified performance	The three metrics are accepted performance				3

<sup>3</sup> European Commission (2015) *Better regulation guidelines: Monitoring arrangements and indicators*  
[http://ec.europa.eu/smart-regulation/guidelines/tool\\_35\\_en.htm](http://ec.europa.eu/smart-regulation/guidelines/tool_35_en.htm)

aspect	metrics across the EU.				
3.2 Use of familiar and accepted normative references	Relies on National Calculation Methodologies of other EN/ISO standards	0	1	2	3
<b>4. Easy</b>					
4.1 Easily and cost effectively verifiable	The calculation methodologies and input data are widely available/understood	0	1	2	3
4.2 Accredited independent testing and verification	Verification can be provided by EPC evaluators, engineers and permitting authorities	0	1	2	3
<b>5. Robust</b>					
5.1 Based on scientifically robust data and methods	National Calculation Method (NCM) method and the resulting accuracy of the modelling varies by Member State and the software/simulation used	0	1	2	3
5.2 Supports comparability at project and local level	Comparisons can be made for functionally equivalent designs and buildings in the local/regional market	0	1	2	3
5.3 Supports comparability at wider level	Outside of a specific region the results need to be understood in terms of EU climate zones	0	1	2	3
5.4 Significant potential benefits or trade-offs	Near zero energy performance may require more energy intensive building materials and excessive air tightness	0	1	2	3
5.5 Mitigation or links to other MOs feasible	Combined calculation of operational and embodied GWP in B1.	0	1	2	3

## 2.4 The selection and analysis of 'field studies'

As has already been described, indicator identification will be informed by detailed analysis of a selection of field studies of building projects. In this section, the methodology for selection and analysis of the field studies is briefly described.

Projects that form part of field studies will have implemented improvements related to the macro-objectives, or alternatively will have gathered practical experience and insight from the piloting of specific calculation or evaluation methodologies.

### 2.4.1 Selection of the field studies

Field studies will provide a source of primary evidence. For the purpose of this study, a field study is defined as follows:

*Monitoring and evaluation studies of selected clusters of buildings with similar characteristics, either new-build or renovation, where major environmental improvements have been made against one or several of the defined macro-objectives.*

*The clusters of buildings could be spatially concentrated (e.g. an entire housing development or masterplan by a single residential developer or consortium) or be a dispersed group of buildings (e.g. office buildings of a consistent form of construction in different locations but analysed by the same project/study team).*

Field studies will be selected that bring together clusters of buildings that have addressed specific relevant technical aspects of one or more of the macro-objectives.

The study will predominantly make use of existing field studies, as this will minimise the need for primary data collection, whilst facilitating access to a larger pool of buildings.

Box 2.2 lists the field studies selected for analysis by study partners VITO and ALTO Ingenierie. Further details of the specific clusters of buildings analysed by ALTO Ingenierie are provided in Section 2.4. Pilot experience from the development of indicator sets by the Sustainable Building Alliance and CESBA (Common European Sustainable Building Assessment) will also be analysed alongside that of the Green Building Council Finland.

#### *Box 2.3 Field studies selected for analysis*

##### *Field studies with buildings in multiple EU Member States focussing on one macro-objective*

- Office and residential construction/development by Skanska in the UK, Norway, Sweden, Czech Republic, Poland and Hungary (macro-objective 1)
- Office and residential buildings in the UK, Belgium and the Netherlands (macro-objective 2)
- Office and residential buildings in Belgium, Finland, Greece, Italy, Portugal, Lithuania, Netherlands, Hungary, Spain and France subjected to air quality monitoring (macro-objective 4)
- Office and residential buildings in the UK, Germany, the Netherlands and Spain that have been designed to be climate change resilient (macro-objective 5)
- Office and residential buildings in Austria, Czech Republic, Germany, Greece, Norway, Slovenia and Sweden to which Life Cycle Costing and modified valuation methodologies have been applied (macro-objective 6)

##### *Field studies that are cross-cutting for several macro-objectives*

- New and renovated buildings whose performance has been reported on using the Green Building Council Finland building performance indicator set
- Residential/mixed used masterplans and office schemes (France/Belgium), being projects which VITO and ALTO Ingenierie have been directly involved in the execution of (macro-objectives 1-4,6).
- Residential/mixed used masterplans and office schemes (France/Belgium), projects which VITO and ALTO Ingenierie have been directly involved with and which have multiple certifications (BREEAM, HQE, DGNB and/o LEED)

### **2.4.2 Analysis of the field studies**

The analysis will focus on implementation experience at project level. For the specific improvement measures on each project, the related targets, benchmarks or indicators used to measure the performance improvement will be identified and analysed. It will also consider the role of project processes, drivers and responsibilities within the design team.

Some of the field studies will draw upon monitoring and testing in the field, e.g. IAQ testing post-completion/during occupation. In these cases, the nature of the field experience analysed will be different. The focus will instead be on findings that guide the design/specification of robust monitoring and testing regimes.

#### *Box 2.4 Framework for analysis of the field studies*

1. *How has the specific macro-objective been translated into action and improvement at project level?*

2. *How was the performance improvement(s) measured and what was the associated methodology?*

*As appropriate to the nature of the macro-objective. In addition, there should be a specific focus on identifying any trade-offs and relationships between the macro-objectives.*

3. *What lessons can be learnt from the experience of measuring and verifying the performance improvement(s)?*

Professional evaluations of how practical the indicators are to use and how successful (or unsuccessful) they are as a tool to monitor and measure performance.

*If available, post occupancy evaluation findings and issues identified e.g. performance gaps.*

### **2.4.3 Use of supplementary 'cross-check' evidence**

The number of field studies that can be analysed will be constrained by the resources available. This means that the findings cannot be presented as statistically relevant. For this reason, the focus will instead be on ensuring comprehensiveness, so as to ensure that any gaps in the technical scope and coverage of the field studies are addressed.

The information gathered from the field studies will therefore be cross-checked using a range of supplementary evidence. This 'cross-check' evidence has been gathered in order to obtain a broad picture of experience relating to each macro-objective, reflecting a range professional, regulatory, cultural and technical contexts.

The following broad types of evidence have been collated and analysed:

- Building permitting requirement implementation *e.g. Netherlands new-build GWP calculation requirement, Madrid water use ordinance*
- Problem analysis based on broad professional experience *e.g. Arup structural design indicator development for ISE (Institute of Structural Engineers)*
- Collaborative EU research project findings *e.g. ENSLIC Building Intelligent Energy Europe LCA pilot (seven Member States)*
- Major multi-criteria assessment scheme criteria *i.e. as initially reviewed for the macro-objectives – BREEAM (CSBE), DGNB, HQE, iiSBE, LEED*
- Harmonisation projects led by standards bodies (CEN/TC 350, EN 15978/15804), certification schemes (*SB Alliance, Common metrics*) and public authorities (*CESBA, Building Signature*)

The cross-check evidence consists of evidence from primary and secondary sources. This included interviews with personnel involved in criteria development and implementation related to BREEAM, DGNB, HQE (non-residential) and VERDE. These interviews focussed on operational experience with selected relevant criteria from these schemes. A follow-up survey with accredited auditors of these schemes in the UK, Germany, France and Spain is currently being undertaken.

*Box 2.5 Framework for analysis of major multi-criteria assessment schemes*

- What is the history and background to inclusion/design of these criteria?
- What has been the experience and feedback in using and assessing these criteria?
  - How readily available and accepted are the methodologies and data used?

- How much training/prior knowledge is required to use them?
- Have they raised any specific challenges for the building types we are focussing on? *i.e. office, residential*
- How easy/cost effective are they to verify in practice?
- o To what extent have certified schemes been able to achieve improvements?
- o What improvements/revisions to these issues might be considered (or are proposed) for the future?

*Overarching questions*

- o Is any further harmonisation of these criteria planned? *e.g. with other standards/building certification schemes/indicators, via SB Alliance participation*
- o Is their evidence of any of these criteria being used in public procurement, building permitting and/or local planning requirements?

## **2.5 Building clusters analysed by ALTO Ingenierie**

The field studies include seven projects which study partner ALTO Ingenierie has been directly involved with. These comprise residential/mixed used masterplans and office schemes. The projects are grouped into three clusters, according to the building typology:

- Cluster 1 'ALTO offices – new-build'
- Cluster 2 'ALTO offices – renovation'
- Cluster 3 'ALTO – residential masterplan'

The clusters have been analysed for each macro-objective that they are relevant to. If there is no significant difference between new-build and renovated offices, they are grouped as well (for instance, in the case of macro-objective 4: healthy and comfortable spaces).

The project are cross-cutting for experience relating to the macro-objectives, as they have multiple building certifications according to multi-criteria assessment schemes: BREEAM, Habitat & Environnement, HQE, DGNB and/or LEED. Each of the three clusters is described in more detail in the following sections of the report.

Because the certification scheme criteria evolve over time this has lead to different versions of the same certification scheme being used. Furthermore, variations of a scheme can also correspond with the geographical location (e.g. BREEAM UK versus BREEAM NL), building type (e.g. residential or non-residential) or design stage (e.g. design versus in-use).

As a result, the certification scheme and the criteria versions used are specifically mentioned for each project. The analysis for each project covers the methods, tools, databases and indicators associated with those specified versions of the certification scheme. This means that the issues raised might already have been addressed in subsequent reversion of a certification scheme.

### **2.5.1 Cluster 1: ALTO offices – new-build**

This cluster consists of three new-build office projects from the building practice of ALTO ingénierie.

CBKII is an office complex in Luxembourg with triple certifications (HQE, BREEAM and DGNB). It consists of two buildings, named "Kennedy" and "Tour". The complex includes



office spaces, corporate catering and a four-level underground car park. The versions used are: HQE v2011, BREEAM v2009 and DGNB v2010 (pilot version).

La Marseillaise is a high-rise office tower in Marseille, designed by Jean Nouvel and double certified (LEED, HQE). The building consists of 31 floors of office spaces, including a corporate catering. The existing building was demolished to make place for the current project. The versions used are: HQE v2013, LEED v3 (2009).

ZENORA is a new-build office building with eight floors. It is certified according to HQE, BREEAM and HQE performance. The versions used are: HQE construction v2008, BREEAM v 2009 and HQE performance.

Table 2.1 Cluster 1 schedule of buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
Kennedy CBKII	Central-Europe, Luxembourg	Office: medium-rise	New-build	9 storeys 3 basements 15 619 <sup>2</sup> SHON <sup>4</sup>	Under construction
Tour CBKII	Central-Europe, Luxembourg	Office: high-rise	New-build	18 storeys 3 basements 26 903m <sup>2</sup> SHON	Under construction
La Marseillaise	Southern Europe, Marseille (FR)	Office: high-rise	New-build	31 storeys	Post-design
Zenora NODA	Central-Europe, Paris (FR)	Office: medium-rise	New-build	7 storeys; net area 23.600 m <sup>2</sup>	In-use

## 2.5.2 Cluster 2: ALTO offices – renovation

This cluster consists of three refurbished office projects from the building practice of ALTO ingénierie.

EULER is a major refurbishment of a large office building (built in 1957 – 1959). Refurbishment works consisted of: Renovating the building fabric - new roof, new windows, new glazed wall; and renovating the building systems - HVAC, sanitary and security systems. The project is triple certified (HQE, BREEAM, LEED) and in addition has a BBC renovation label. The versions used are: HQE refurbishment v2010, BREEAM v2009, LEED v3 (2009).

Similarly, MEDERIC is also a major refurbishment of a large office building, with the same kind of refurbishment works. The project is BREEAM (in-use and non-residential) and HQE certified, in addition to a BBC renovation label. The versions used are HQE refurbishment v2010, BREEAM v2009 and BREEAM in-use v2015.

Finally, LAFFITE LAFAYETTE is a refurbishment of a building with 1 level underground and 7 floors of office spaces. The project is HQE certified and has a BBC renovation label. The version used is HQE refurbishment v2009.

<sup>4</sup> Surface HorsOeuvre Nette - Adjusted gross floor area, calculated by deducting the floor areas of non-convertible lofts and basements, open areas, parking spaces, agricultural units, and greenhouses for production use from the Surface Hors Oeuvre Brute (SHOB) of the same building - see Section R. 112-2, Code de l'urbanisme (French Town Planning Regulations). SHO = Gross floor Area

Table 2.2 Cluster 2 schedule of buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
Euler	Central-Europe, Paris (FR)	Office: medium-rise	Refurbishment	9 storeys; net area 13.300 m <sup>2</sup>	In-use
Mederick	Central-Europe, Paris (FR)	Office: medium-rise	Refurbishment	10 storeys; net area 6 619m <sup>2</sup>	In-use
Laffite Lafayette	Central-Europe, Paris (FR)	Office: medium-rise	Refurbishment	8 storeys; net area 5 589 m <sup>2</sup>	In-use

### 2.5.3 Cluster 3: MacDonald masterplan (Paris, France)

Boulevard Mac Donald is an urban redevelopment masterplan in the north of Paris, France. It centres around the rehabilitation of the old MacDonald warehouses. It consists of 15 multi-family apartment buildings. A kindergarten has been integrated into a building and shops located on the ground floor. A part of the rehabilitation has integrated offices and a school, but this part is not included in the analysis.

ALTO Ingénierie was environmental consultant for all the 15 building units. The buildings had to achieve the following certifications: "Habitat & Environment (H&E)"<sup>5</sup> and "Bâtiment Basse Consommation (BBC)"<sup>6</sup>.

Table 2.3 Cluster 3: Boulevard Mac Donald masterplan, schedule of buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
N5	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	44 apartment units – 3 571m <sup>2</sup> SHON	In-use
N6	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	60 apartment units – 4 544m <sup>2</sup> SHON	In-use
S6	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	43 apartment units – 3 749 m <sup>2</sup> SHON	In-use
S7	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	82 apartment units – 7 355m <sup>2</sup> SHON	In-use
E1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	147 apartment units – 4 174m <sup>2</sup> SHON	In-use
N1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	45 apartment units – 5 041m <sup>2</sup> SHON	In-use
N2	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	90 apartment units – 5 905m <sup>2</sup> SHON	In-use
S1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	50 apartment units – 3 558m <sup>2</sup> SHON	In-use
S2	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	138 apartment units – 8 021m <sup>2</sup> SHON	In-use
O1	Central-Europe,	Residential:	New-build	78 apartment	In-use

<sup>5</sup> Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

<sup>6</sup> BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

	Paris (FR)	Apartment block		units – 5 910m <sup>2</sup> SHON	
N3	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	84 apartment units – 6 859m <sup>2</sup> SHON	In-use
N4	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	61 apartment units – 4 727m <sup>2</sup> SHON	In-use
S3	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	128 apartment units – 3 458m <sup>2</sup> SHON	In-use
S4	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	33 apartment units – 2 675m <sup>2</sup> SHON	In-use
S5	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	42 apartment units – 3 279m <sup>2</sup> SHON	In-use

### **3. Macro-objective 1: Greenhouse gas emissions from building life cycle energy use**

#### **3.1 Defining the macro-objective's scope and focus**

##### **3.1.1 Policy and technical background**

As was described in Working Paper 1, the construction and renovation of buildings in order to reduce energy use and CO<sub>2</sub> emissions is a central environmental policy objective for Europe. The recast *Energy Performance of Buildings Directive 2010/31/EU (EPBD)*<sup>7</sup> sets out requirements for buildings that contribute towards ambitious EU targets for energy efficiency by 2020. It requires Member States to transpose the following into national legislation:

- Minimum, cost optimal energy performance requirements for new buildings, for major renovation of buildings and for the replacement or retrofit of building elements (e.g. heating and cooling systems, roofs, walls);
- The inclusion of Energy Performance Certificates in all advertisements for the sale or rental of buildings;
- All new buildings must be 'nearly zero energy' by 31 December 2020 and all public buildings by 31 December 2018.

National plans to meet the 'nearly zero energy' targets should set requirements for primary energy use expressed in total primary energy use in kWh/m<sup>2</sup> per annum. It is understood that, based on their plans and targets, this is therefore the reference unit of performance measurement for at least fifteen Member States.

The EPBD lays down requirements that shall apply to both new buildings and major renovations, with the latter defined as cases where:

- (a) the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated; or*
- (b) more than 25 % of the surface of the building envelope undergoes renovation;*

Annex I of the recast EPBD then specifically refers to the classification for energy calculation purposes of single family houses (of different types), apartment blocks and offices. The Energy Efficiency Directive 2012/27/EU<sup>8</sup> introduces the additional term 'deep' renovation.

##### **3.1.1.1 Scope and definition of National Calculation Methods**

The EU Directive 2010/31/EU (recast) on the energy performance of buildings (EPBD) states that reporting on the energy performance of a building shall include '*an energy performance indicator and a numeric indicator of primary energy use*' and that the methodology should take into account European standards.

Annex I of the Directive lays down a common framework for calculation of a buildings energy performance. This can be understood as a minimum scope for the delivered energy uses to be modelled within a National Calculation Method, as indicated in Table 3.1. The need to focus on measures to avoid overheating and

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<sup>7</sup> Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

<sup>8</sup> Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

improve indoor climatic conditions is also highlighted. This specific performance aspect is addressed in detail in Chapter 7 under macro-objective 5.

*Table 3.1 Common general framework for calculation of a building's energy performance as laid down by the EPBD (recast)*

Type of performance aspect	Performance aspects
Minimum aspects of thermal characteristics to take into consideration	(a) the following actual thermal characteristics of the building including its internal partitions: (i) thermal capacity; (ii) insulation; (iii) passive heating; (iv) cooling elements; and (v) thermal bridges;
	(b) heating installation and hot water supply, including their insulation characteristics
	(c) air-conditioning installations
	(d) natural and mechanical ventilation which may include air-tightness
	(e) built-in lighting installation (mainly in the non-residential sector)
	(f) the design, positioning and orientation of the building, including outdoor climate
	(g) passive solar systems and solar protection
	(h) indoor climatic conditions, including the designed indoor climate
	(i) internal loads
Aspects whose 'positive influence' shall be taken into account	(a) local solar exposure conditions, active solar systems and other heating and electricity systems based on energy from renewable sources;
	(b) electricity produced by cogeneration;
	(c) district or block heating and cooling systems;
	(d) natural lighting.

Source: European Commission (2010)

### 3.1.1.2 The role of EPCs in the property market

The concept of EPCs was a key concept introduced into the EU property market by the EPBD, being intended as a market mechanism to enable owners or tenants to compare and assess a building's energy performance. However, as will be discussed further in Section 3.2.1.1, implementation of the EPBD has not been consistent across the EU, resulting in a range of different National Calculation Methods and EPC formats.

In seeking to identify common indicators it is therefore important to identify from both the EU policy framework, and the ways in which it has been transposed by Member States, a common reference basis for calculating and reporting on operational energy use and CO<sub>2</sub> emissions.

The recast EPBD Directive laid down in Article 11(9) the intention of the Commission to 'adopt a voluntary common European Union certification scheme for the energy performance of non-residential buildings'. Following an initial market study in 2014 which highlighted why such a scheme would be of value <sup>9</sup>, the EU Voluntary Certification Scheme (EVCS) is now being developed by DG Energy with the support of a consortium led by French research centre CSTB <sup>10</sup>. Further details of this process and the emerging proposals are provided in Section 3.2.5.3.

### **3.1.1.3 Broadening of the focus from operational to embodied energy and CO<sub>2</sub> equivalent emissions**

Whilst there is no current intention to introduce policy that requires reporting on embodied energy or CO<sub>2</sub> equivalent emissions, the European Commission has taken steps to support the adoption of a life cycle approach by industry.

The Construction Products Regulation <sup>11</sup> was preceded by a mandate to CEN/TC 350 in 2004 <sup>12</sup> to develop standards for assessment of the life cycle environmental performance of construction products and buildings as a whole. The resulting standards EN 15804 and EN 15978 include an indicator for Global Warming Potential (GWP) for which the unit is kg of CO<sub>2</sub> equivalents. Indicators of resource use also include renewable and non-renewable use of primary energy as both a raw material and as a secondary fuel.

The pilot phase of the European Commission's Product Environmental Footprint (PEF) <sup>13</sup> includes a number of building products – namely decorative paints, hot and cold water supply pipes, metal sheets, photovoltaic panels and thermal insulation. The method includes a climate change impact category for which the indicator is kg of CO<sub>2</sub> equivalents, as well as an indicator combining fossil fuel and mineral depletion.

The potential influence of the PEF on future standards for building environmental assessment will, to an extent, depend on the outcomes from this pilot. In the short term, initial feedback presented at the November 2015 mid-term conference for the pilot process highlighted the need for convergence with the existing CEN/TC 350 standards <sup>14</sup>. Stakeholders emphasised the level of uptake and acceptance of these standards in the market.

### **3.1.2 The intended scope and focus**

The macro-objective is to minimise the total GHG emissions along a buildings lifecycle, with a focus on building operational energy use emissions and embodied emissions along the life cycle of a building.

In practical terms, the macro-objective will focus on projects which estimate Global Warming Potential based on CO<sub>2</sub> equivalent emissions (sometimes referred to as a 'carbon footprint analysis'). This is likely to be with reference to various standards or methodologies e.g. EN 15978, PAS 2050 (UK).

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<sup>9</sup> Triple E Consulting, *European Market study for a voluntary common European Union certification scheme for the energy performance of non-residential buildings*, Report prepared for DG Energy, 26 November 2014

<sup>10</sup> Construction 21, *Enabling the European Common Voluntary Certification Scheme (VCS) for non-residential buildings*, Website accessed May 2016, <http://www.construction21.org/community/pg/groups/25189/vcs-project/>

<sup>11</sup> 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

<sup>12</sup> European Commission, *Development of horizontal standardised methods for the assessment of the integrated environmental performance of buildings*, Standardisation mandate to CEN, M/350 EN, 29th March 2004

<sup>13</sup> Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (OJ L-124 4.5.2013 p-1)

<sup>14</sup> European Commission, *Mid-term conference on the Environmental Footprint pilot phase*, 3-4 November 2016.

A specific focus, alongside the inclusion of embodied impacts, could also include the potential for gaps in calculated and measured energy consumption in the use phase.

### 3.2 Cross-cutting evidence of the macro-objective's implementation

#### 3.2.1 National and regional initiatives

##### 3.2.1.1 Minimum performance requirements for new and renovated buildings

The energy use of office and residential buildings is regulated at national level by building regulations and ordinances that set minimum performance requirements for both new and renovated buildings, as required by the Energy Performance of Building Directive (EPBD) <sup>15</sup>. These are usually presented on a graded Energy Performance Certificate in kWh/m<sup>2</sup> of total primary energy use and usually also optionally in kg CO<sub>2</sub>.yr eq emissions per m<sup>2</sup> <sup>16</sup>. Figure 3.1 provides an example from Germany.

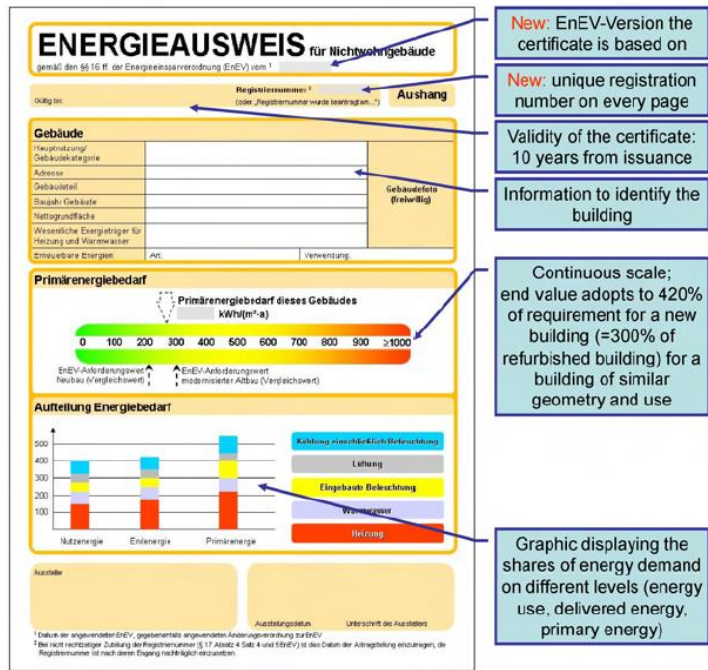


Figure 3.1. Example EPC format from Germany with graded overall performance  
Source: European Union (2016)

In some Member States the reporting on performance is further divided into requirements for heating and cooling, such as in Italy – as illustrate in Figure 3.2. Under the recast EPBD, an EPC must be provided for all new and existing buildings that are sold on the property market.

<sup>15</sup> Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)

<sup>16</sup> Concerted Action EPD (2016) *Implementing the Energy Performance of Buildings Directive*, Intelligent Energy Europe programme

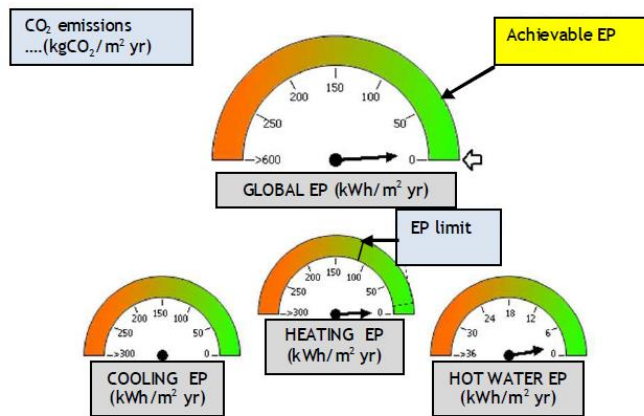


Figure 3.2. Example EPC format from Italy divided into delivered energy uses  
Source: European Union (2016)

A survey carried out in 2015 illustrated the diversity in National Calculation Methods that are specified across the EU<sup>17</sup>. Measured energy can be reported in 37% of Member States for residential and 51% for non-residential buildings. 74% of the methods use the same calculation method, with only relatively small differences that usually relate to simplifications introduced for renovated buildings, as well as omissions relating to a number of new technologies (e.g. cogeneration) and passive solutions (e.g. natural ventilation). 54% are in line with CEN standards, although items within Annex A of EN 15603, which specifies building data to be included within calculations, were not addressed.

Under the recast Energy Performance of Buildings Directive 2010/31/EU, Member States are additionally required to prepare national plans to ensure that all new buildings are 'nearly zero energy' by 2020. This is defined in Article 2(2) of the Directive as:

*'...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.'*

The national plan should set requirements for primary energy use expressed in kWh/m<sup>2</sup> per annum. Intermediate requirements shall be set for 2015. The most recent progress assessment by the European Commission showed that fifteen Member States had already set intermediate targets, expressed either in kWh primary energy /m<sup>2</sup>.yr or as EPC levels<sup>18</sup>. Only three Member States are understood to have set targets for major renovations.

### 3.2.1.2 An increasing focus on the quality of construction

There is an increasing focus by Member States on the role of building designers, service engineers, energy consultants and construction contractors in ensuring the quality and performance of completed buildings. Evidence has shown that a focus on quality is important to ensure that the completed building fabric has a low level of air infiltration (i.e. it is air tight and does not leak air) and minimal thermal bridges where heat can be conducted through the buildings structure from outside to inside (or vice versa). The correct installation, commissioning and functioning of HVAC services and renewable energy systems is also an important aspect.

<sup>17</sup> CSTB France and TSUS Slovakia, *Technical assessment of national/regional calculation methodologies for the energy performance of buildings*, Final report for the European Commission, January 2015

<sup>18</sup> COM(2013) 483 Report from the Commission to the European Parliament and the Council, Progress by Member States towards Nearly Zero-Energy Buildings, Brussels, 7.10.2013



Recognising the importance of air tightness, at least 11 Member States now require some form of testing of the integrity of the building fabric at national or regional level, with Denmark, Ireland, France and the UK setting minimum requirements in their building regulations<sup>19</sup>. Only Denmark is understood to currently legally require thermal imaging to test construction quality<sup>20</sup>. A challenge at EU level is comparability, because the BPIE (2015) have identified that testing standards and metrics vary, as illustrated in Figure 3.3.

A range of collaborative EU funded projects have focussed attention on this aspect in recent times. Notable examples include ASIEPI, QUALICHECK and PERFORMER. These three projects are briefly reviewed in Section 3.2.4.2.

The QUALICHECK project highlighted a range of initiatives to address quality and compliance issues, including:

- Harmonised product performance formats and databases, to support the use of more accurate input data;
- Certification frameworks for the installation of renovation features such as cavity walls and windows;
- Competent tester and quality management schemes for building airtightness which in turn reduce ensure that accurate values are obtained;

Two examples of specific national practices illustrate the importance of quality. In France, surveys have shown that level of non-compliance with ventilation regulations can reach 50%<sup>21</sup>. A new air permeability minimum standard was introduced in 2012 and was accompanied by a requirement for verification – either on a systematic or sample basis<sup>22</sup>. According to EU airtightness associations, France now accounts for nearly 50% (930) of qualified testers in those countries which have a regulatory requirement.

In Ireland, a new quality assurance scheme called QualiBuild has been established as part of the EU funded BUILD-UP Skills project<sup>23</sup>. The aim of the project is to improve the skills of the building trades to deliver high energy performance buildings. Training under the programme may in the future become a statutory requirement. The new Irish residential environmental performance rating tool currently under development will include specific credits on quality assurance. The areas focussed on are described further in Section 3.4.1.3.

The importance of quality in renovation is recognized in the loan requirements to participate in Germany's federal building renovation programme. Compliance with the KfW Bank's "KfW Efficiency House" targets (described in kWh/m<sup>2</sup>) is dependent on a series of quality and compliance checks<sup>24</sup>.

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<sup>19</sup> Heike.E-K, Erhorn.H, Lahmidi.H and R.Anderson, *Airtightness requirements for high performance building Envelopes*, Published by Asiepi, 2010 and ATTMA, *Measuring air permeability of building envelopes*, Technical standard L2, October 2010

<sup>20</sup> Asiepi (ASessment and Improvement of the EPBD Impact), *Analysis of Execution Quality Related to Thermal Bridges*, 18th October 2009

<sup>21</sup> Qualicheck, *Regulatory compliance checks of residential ventilation systems in France*, Fact sheet No.6, November 2015

<sup>22</sup> Qualicheck, *Building regulations can foster quality management: The French example on building air tightness*, Fact sheet No.1, January 2015

<sup>23</sup> QualiBuild, Website accessed May 2016, <http://www.qualibuild.ie/>

<sup>24</sup> KfW, *Housing, home modernisation and energy conservation – Energy-efficient refurbishment*, <https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilie/>



Figure 3.3 Air tightness requirements across Europe

Source: BPIE (2015)

Gradual adoption across the EU of the German Passivhaus standard has also raised awareness of quality issues, including as it does a focus on building fabric integrity and post-construction testing<sup>25</sup>. In some cases this standard has been promoted by local government, for example in the case of Hannover in Germany.

### 3.2.2 Building permitting and planning requirements

In a number of Member States, there have been moves to extend the focus of voluntary reporting and regulatory permitting to address embodied primary energy and CO<sub>2</sub> equivalent emissions along a buildings life cycle. Leading examples that can be cited are in the Netherlands, the UK and France.

#### 3.2.2.1 Life cycle Greenhouse Gas emissions reporting, the Netherlands

In January 2013, the Netherlands introduced a new environmental requirement in the Dutch Building Decree to calculate and report on Greenhouse Gas emissions (GWP) and the depletion of abiotic resources (ADP) for structural components of

<sup>25</sup> Passipedia, *Thermal bridges*, Passivhaus Institut, [http://www.passipedia.org/passipedia\\_en/basics/building\\_physics\\_-\\_basics/heat\\_transfer/thermal\\_bridges#what\\_defines\\_thermal\\_bridge\\_free\\_design](http://www.passipedia.org/passipedia_en/basics/building_physics_-_basics/heat_transfer/thermal_bridges#what_defines_thermal_bridge_free_design)

residential buildings and office buildings (over 100m<sup>2</sup>). The reporting must be provided upon application for a building permit <sup>26</sup>.

The two reporting requirements are to be fulfilled according to the Netherland's Environmental Assessment Method for buildings and civil engineering works – Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken. Benchmarking to set performance requirements may be considered once sufficient data has been collected from building permits.

### **3.2.2.2 Embodied carbon as an 'allowable solution', United Kingdom**

The potential to develop an embodied CO<sub>2</sub> compliance route for the UK's 'zero carbon' building permitting requirement, which would originally have come into force in 2016, was explored by an independent, industry-led task force in 2014. The Task Force put forward recommendations to the UK Government on a set of common implementation rules for EN 15978 <sup>27</sup>.

The main justification was that in order to meet the zero carbon requirement, embodied CO<sub>2</sub> would become more important than operational emissions, rising to approximately 30-70% of life cycle emissions even before occupation of the building. The intention was that these rules could then be used as a cheaper means to offset the more expensive CO<sub>2</sub> emissions reductions associated with low or zero carbon energy generation.

The Task Force identified ten local authorities in the UK that had already requested assessments of embodied CO<sub>2</sub> emissions or provided guidance as part of the planning permitting process.

### **3.2.2.3 Voluntary reporting on embodied CO<sub>2</sub> emissions, France**

The French government is anticipated to introduce a new voluntary display scheme as part of the revised building energy regulation in 2018-20 – the 'Environmental Building Declaration'. This is foreseen to include reporting on both operational and embodied life cycle stages, and for both energy and greenhouse gas emissions. In the interim, a private scheme focussing on embodied CO<sub>2</sub> emissions (BBCA) has been initiated by the research body CSTB (see Section 3.2.2.3).

## **3.2.3 Public and private sector building practices**

A number of public and private sector organisations can be identified that can be considered to be front runners in the applied assessment of operational and embodied CO<sub>2</sub> equivalent emissions. These include:

- the German DGNB multi-criteria assessment scheme and the Federal Building Ministry's Assessment System for Sustainable Building (BNB) <sup>28</sup>, which both require an LCA to be carried out (see Section 3.4.1);
- Consultant engineers that have sought to specialise in this field, such as Sturgis Carbon Profiling (UK) and Arup (internationally);
- Major EU construction contractors that have sought to specialise in this field, such as Skanska plc (see field study Cluster 2);

<sup>26</sup> Bouwbesluit 2012, *Besluit van 29 augustus 2011 houdende vaststelling van voorschriften met betrekking tot het bouwen, gebruiken en slopen van bouwwerken, Artikel 5.9*. Duurzaam bouwen, Netherlands, <http://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012/hfd5/afd5-2/art5-9>

<sup>27</sup> Embodied Carbon Industry Task Force, *Proposals for standardised measurement method and recommendations for zero carbon building regulations and allowable solutions*, June 2014, UK

<sup>28</sup> Federal Ministry for the Environment, the Protection of Nature, Construction and Nuclear Safety, Assessment system for sustainable building, <http://www.nachhaltigesbauen.de/sustainable-building-english-speaking-information/assessment-system-for-sustainable-building.html>

Industry-led organisations and initiatives can also be identified that have sought to build on practitioners experience by developing common methodologies and reporting protocols. These include the HQE Performance pilot and associated LCA tools and databases (France) , the Embodied Carbon Industry Task Force (UK) <sup>27</sup> and the European Network of Construction Companies for Research and Development (ENCORD) <sup>29</sup>. Investor reporting schemes are also playing an important ongoing role in reporting on operational energy use and CO<sub>2</sub> equivalent emissions.

Valuable lessons for the development of indicators can potentially be learnt from these initiatives, in particular in relation to how the wider adoption of embodied CO<sub>2</sub> equivalent emissions calculations could be supported.

*In the following sub-sections the lessons from selected initiatives are briefly summarised.*

### **3.2.3.1 Operational energy and CO<sub>2</sub> equivalent emissions: Investor reporting and benchmarking schemes**

As was identified in Working Paper 1, a range of investor reporting schemes used in the EU property market have been designed to support reporting for property portfolios. The examples analysed were:

- The Environment Code, Investment Property Databank (IPD) (Origin: UK)
- Construction and Real Estate, the Global Reporting Initiative (Origin: International)
- Global Real Estate Sustainability Benchmark (GRESB), Green Building Certification Institute (Origin: USA/Netherlands)
- Green Rating, Green Rating Alliance (Origin: European)
- Real Estate Environmental Benchmark, Better Buildings Partnership (Origin: UK)

The commercial properties reported on can include new-build, major renovations and (for the most part) existing stock potentially awaiting renovation. Reporting may in some cases be disaggregated into the 'base building' and, within this building, energy use in tenanted areas.

The scope of use stage (operational) primary energy use reported can have a significant effect on the results. For example, where measured energy assessments are made based on metered consumption data, 'unregulated' non-EPBD energy consumption related to building occupancy will additionally be measured. Conventions for how internal floor areas in m<sup>2</sup> are measured is also highlighted as an issue, as definitions can vary.

A number of groups of investors have investigated in detail the challenges for reporting on and benchmarking the performance of property portfolios. The London Better Buildings Partnership (BBP) sought to identify the key challenges for data collection and comparability <sup>30</sup>. They primarily related to:

1. Normalised reporting: A preference for normalised reporting over absolute reporting on performance as it better reflects the dynamic nature of the property market;
2. Keeping it simple: The need to keep the reporting process simple at the outset, building up complexity only as knowledge of buildings and their performance grows;

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<sup>29</sup> ENCORD, *Construction CO<sub>2</sub>e management protocol – a guide to reporting against the Green House Gas protocol for construction companies*, Version 1.0, May 2012

<sup>30</sup> London Better Buildings Partnership (2010) *Sustainability Benchmarking Toolkit for Commercial Buildings – principles for best practice*

3. Ensuring comparability: The need for an agreed set of industry metrics and indicators, so as to avoid duplication of data collection and to ensure comparability

A 'graduated' approach is referred to whereby the approach to performance measurement can build in sophistication over time. Examples include increased frequency or measurement, increasing levels of detail (e.g. disaggregation by fuel or energy supply, or by floor) and the use of additional normalisation metrics. Other considerations can include adjustments for hours of occupation, weather and voids.

The normalisation of office energy performance to occupational density instead of m<sup>2</sup> is highlighted by the BBP as an advanced option. This can be according to:

- full time equivalent staff,
- workspaces or workstations,
- workspace density.

This form of normalisation appears to be an important consideration, with BBP highlighting that improved organisational performance would not be captured by a simple normalisation based on floor area. This approach is further illustrated by one of the buildings analysed as part of macro-objective 2, field study cluster 4.

### **3.2.3.2 Embodied CO<sub>2</sub> emissions: Sturgis CP, UK**

Sturgis Carbon Profiling have reported on their extensive experience from the analysis of commercial<sup>31</sup> and residential buildings<sup>32</sup> in the UK. Sturgis CP's approach is to optimise performance by identifying the 50 most 'carbon intensive' components. Importantly, all reporting is normalised to m<sup>2</sup> of internal floor space to ensure the comparability of different options. This form of analysis has led to a focus of attention on the impact contribution of structural systems<sup>33</sup> and facades<sup>34</sup>.

#### *Key findings for offices*

For *prestige offices*, Sturgis CP highlight the increasing importance of other life stages as the relative contribution of the operational (use) stage reduces. The nature of the office market, with high turnover of tenants and changes in functional and aesthetic requirements, means that building fabrics may not achieve their design life. Facades are highlighted as a specific area of attention, as they may have a replacement cycle of less than 20-30 years, so a focus on use stage B4 and potentially also end of life stages C1 and C4 would be beneficial.

#### *Key findings for residential properties*

For *domestic properties*, they highlight the life cycle benefits of renovating buildings. This is because of the savings made in the main building elements, because older buildings may be made of more robust materials. Their analysis suggests a focus is required on the life span of new domestic buildings.

#### *Key findings for common structural systems*

Comparative analysis has been carried out of the most *common structural systems* used in modern commercial buildings and residential blocks – including concrete, steel, hybrid and engineered timber systems. Their findings for

<sup>31</sup> Roberts.G, *Whole-life carbon: Prestige offices*, Sturgis Carbon Profiling for Building magazine, 18<sup>th</sup> May 2012, [www.building.co.uk](http://www.building.co.uk)

<sup>32</sup> Roberts.G, *Whole-life carbon: Domestic*, Sturgis Carbon Profiling for Building magazine, 20<sup>th</sup> June 2013, [www.building.co.uk](http://www.building.co.uk)

<sup>33</sup> Papakosta, A, *Whole-life carbon: Structural systems*, Sturgis Carbon Profiling for Building magazine, 19<sup>th</sup> April 2016, [www.building.co.uk](http://www.building.co.uk)

<sup>34</sup> Cheung.L and M.Farnetani, *Whole-life carbon: Facades*, Sturgis Carbon Profiling for Building magazine, 13<sup>th</sup> November 2015, [www.building.co.uk](http://www.building.co.uk)

structures suggest that from a life cycle CO<sub>2</sub> emissions perspective, they can account for 30-64% of embodied emissions.

The design life of structures beyond completion of the building is identified as an important consideration. The potential for buildings to adapt and be flexible to changing needs and uses, as well their subsequent potential for dismantling (as whole elements or modular components) and recycling, has significant influence on their lifespan and end of life environmental impacts respectively.

Specification to ensure recyclability is particularly important for wooden structures so as to avoid landfilling or incineration, which would release sequestered CO<sub>2</sub>, with consideration of preservatives and adhesives that may prevent recycling cited as an example.

In line with the current rules of EN 15978 if the end of life stage was to be omitted, then embodied CO<sub>2</sub>.eq emissions along the life cycle may be underestimated for timber. Inclusion of the emissions results in a +93% variation in the results for the steel frame/Cross Laminated Timber (CLT) system type, as illustrated in figure 3.4. The extent to which this is the case will also depend on the end of life scenarios – an aspect explored further under macro-objective 2, Section 4.2.1.4.

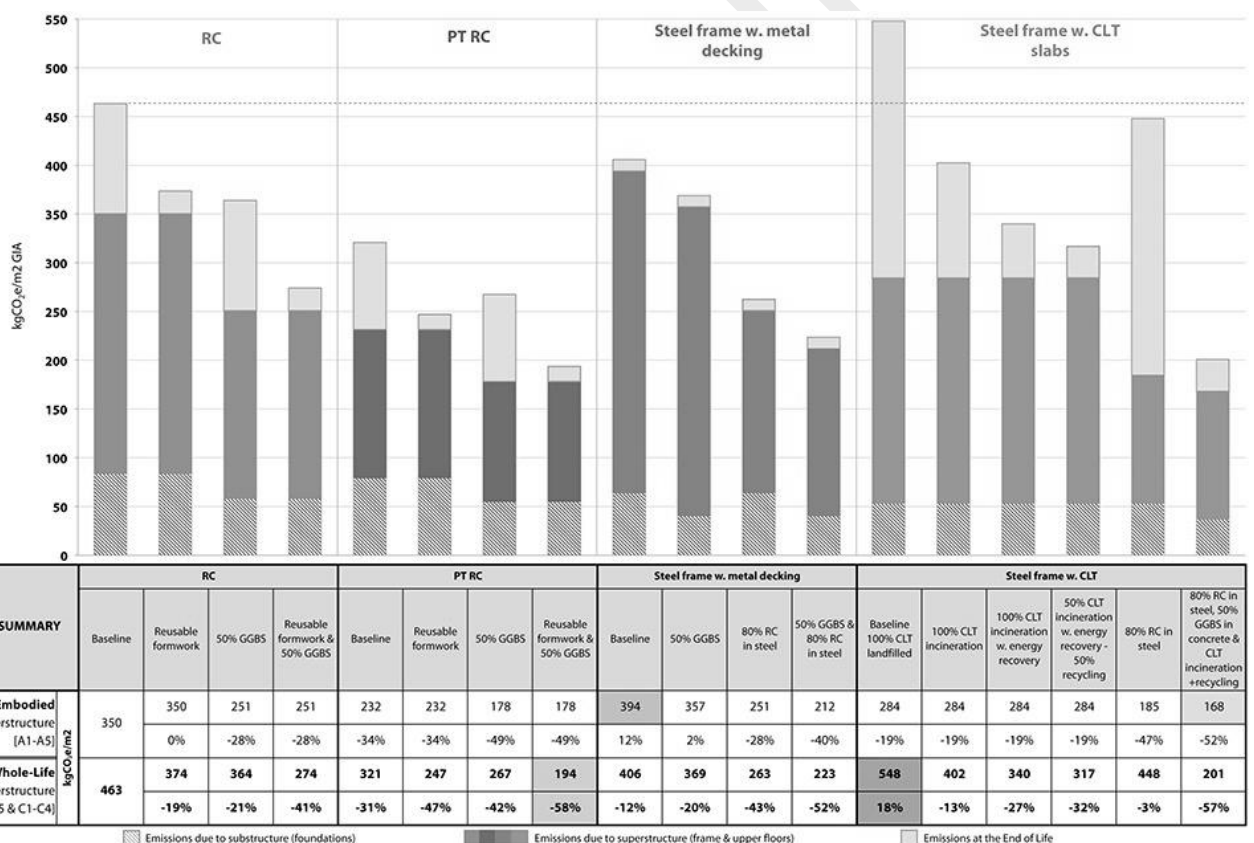


Figure 3.4 Comparison of the CO<sub>2</sub> eq. emissions per m<sup>2</sup> Gross Internal Floor Area (GIA) for the different structural systems analysed

Source: Sturgis Carbon Profiling (2016)

### Key findings for commercial building facades

Sturgis CP have carried out comparative analysis of commercial building facades. The results suggest that from life cycle CO<sub>2</sub> emissions perspective, they can

account for 13-21% of embodied emissions, with glazed systems towards the top end of the range. Their replacement cycle is a key consideration because of the tendency towards the use of flexible curtain wall systems incorporating glazing and louvres. Materials specifications can also influence their recyclability and is linked to that their potential to claim credits under life cycle Module D.

### 3.2.3.3 Embodied CO<sub>2</sub> emissions: 'HQE Performance' pilot project (France)

Given the currently low uptake of LCA by the building industry, the HQE Performance pilot project, which was funded by two French Ministries, is of particular relevance to this study<sup>35</sup>. This is because it provides a consistent analysis of a relatively large pool of buildings (140) consisting of detached houses, apartment blocks and office buildings. Moreover, as was illustrated in Section 3.2.2 the findings are being used to inform voluntary reporting in France.

The aim of the study was to derive reference values to compare building performance. The study included non-renewable primary energy and Global Warming Potential within the impact categories calculated. The buildings were mainly constructed to a 'low energy' standard estimated to consume less than 50 kWh/m<sup>2</sup> net floor area per annum and included a representative range of construction materials and techniques used in France. All life cycle stages were modelled over a reference service life of 50 years with a sensitivity for 100 years.

The contribution of major groups of sub- elements of the building were also analysed and are presented for non-renewable primary energy use and Global Warming Potential in Figure 3.5. The study also provides a good example of how variability in grid CO<sub>2</sub> emissions factors across the EU can influence LCA results. France has low emissions factors because electricity is primarily generated by nuclear power stations. The non-renewable primary energy results are therefore more comparable.

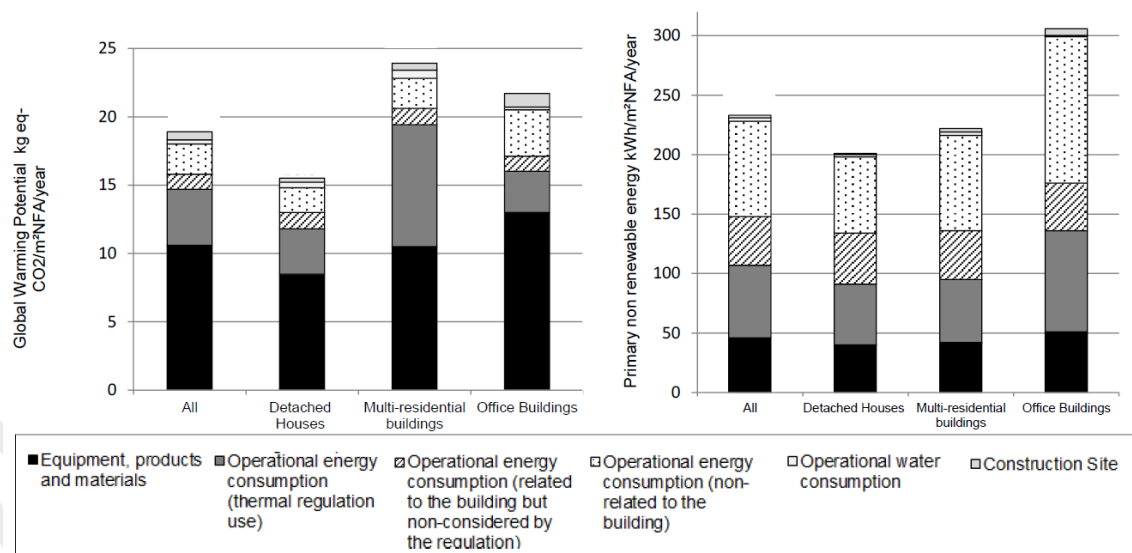


Figure 3.5 Median values for non-renewable energy and GWP indicators for the different types of buildings included in the HQE Performance project

Source: CSTB (2012)

<sup>35</sup> Lebert, A., Lasvaux, S., Grannec, F., Achim, F., Chevalier, J., and J. Hans (2012) A statistical analysis of the environmental performances of low-energy buildings, CSTB, France.

#### **3.2.3.4 Embodied CO<sub>2</sub> emissions: BBCA voluntary labelling scheme, (France)**

In advance of a government-led scheme, a private scheme – Batiment Bas Carbone (BBCA) - was launched in early 2016. The design of the scheme has been informed by the findings from the HQE Performance pilot project, which was described in Section 3.2.3.3 .

The BBCA scheme focusses on new construction and supports reporting on kg CO<sub>2</sub> equivalents/m<sup>2</sup>. Offices and apartment blocks will be supported in the first version, to be followed later in the year by individual homes. Based on these findings, and in order to make the scheme accessible and encourage its use, a number of notable calculation rules have had to be laid down:

- Use of the ELODIE LCA software, which was developed to support the French FDES EPD system;
- The reference service life for a building shall be defined as 50 years;
- Generic (default) data provided may be used to substitute primary data or EPD data from the INIES (HQE) or French Ministry's databases, but this generic reflects the worst case scenario so as to encourage primary data collection;
- A weighting system places priority on the superstructure, foundations, facades and external walls. Reporting on the superstructure is a minimum requirement;
- Additional points can be obtained for the recyclability, dismantle ability and adaptability of the building;

The calculation method as a whole is with reference to EN 15978 and 15804. The recyclability of building elements supports evaluation according to Module D of EN 15978/15804.

#### **3.2.3.5 Embodied CO<sub>2</sub> emissions: Embodied Carbon Industry Task Force (UK)**

In Section 3.2.2 reference was made to the Embodied Carbon Industry Task Force formed in the UK. Although the proposal to use embodied carbon as a compliance route was not implemented, the Task Force nonetheless made a number of recommendations and proposals that are of relevance to encourage the calculation of embodied emissions for buildings:

- A minimum reporting framework is needed, based on EN 15978;
- A building materials emissions database is needed to support such a framework, as already exists in Germany, the Netherlands and France. The Bath ICE database is commonly used, but dates from 2011;
- Minimum boundaries should be set, with EN 15978 A1-5 proposed as the starting point;
- A minimum scope should be set, with the substructure and superstructure of a building proposed as the starting point;
- Yield losses (wastage) from the cutting of materials may reach 50% and should be considered in the future.

#### **3.2.3.6 Comparison of generic and EPD data, ENIES database (France)**

The challenges relating to data have been consistently highlighted in relation to experience with life cycle assessments. The use of generic data is a specific aspect which creates uncertainty. Generic data is understood to refer to proxy data at a national level that will not be able to describe the environmental impacts of a product sold by a specific manufacturer.



As there are several different potential reference guidelines, databases use different assumptions and this hinders comparability of results<sup>36 37</sup>. Previous studies have compared the use of EU building LCA tools and databases suggest a variance of up to 10%<sup>38</sup>.

Lasvaux et al (2015) made a study of the potential for variations in results based on the use of generic and primary data<sup>38</sup>. The study was based on a comparison between the ecoinvent generic database and the French ENIES product EPD database (cradle to grave). The study found that GWP can vary by 26%, but that positive and negative variations occur which can cancel each other out (see indicative results in Figure 3.6). Possible reasons for variations included recycled content, different raw material quantities for the same product and grid electricity emissions factors.

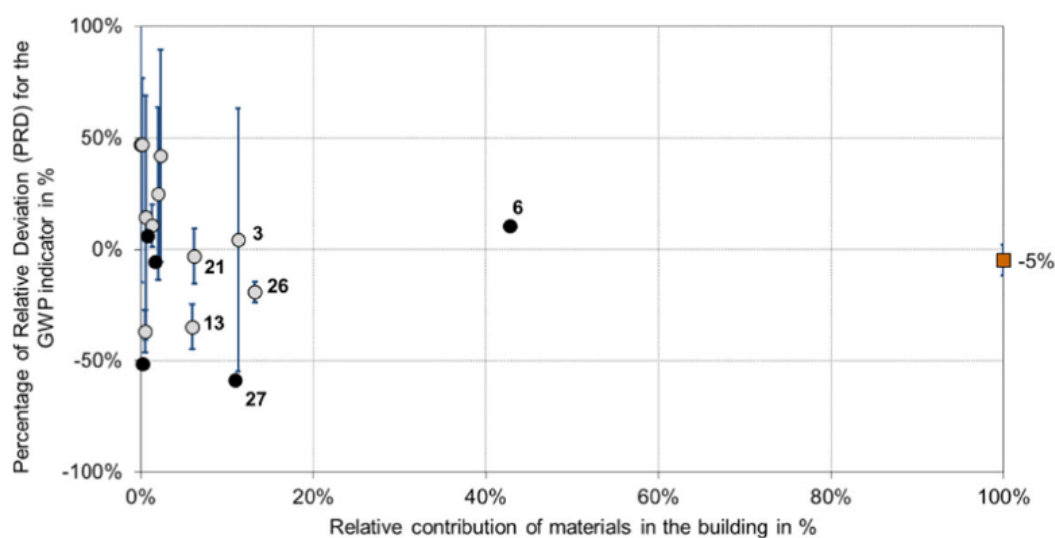


Figure 3.6. Percentage of Relative Deviation (PRD) function of the relative contribution of materials in a building case study, representing the variability of the data

Source: Lasvaux et al (2015)

### 3.2.4 Collaborative EU projects

A range of collaborative EU funded projects can be identified that have looked at issues relating to operational and embodied primary energy and CO<sub>2</sub> equivalent emissions. These projects fall into a number of distinct categories:

- Supporting EPBD implementation: The Intelligent Energy Europe programme has supported a range of projects, including the rolling Concerted Action initiative and the BUILDUP initiative;
- Addressing the gap between design and actual performance: Notable projects include ASIEPI, QUALICheck and PERFORMER;

<sup>36</sup> De Wolf.C, Personal interview carried out by VITO, April 2016

<sup>37</sup> De Wolf.C, Yang.F, Cox.D, Charlson.A, Hattan.A.S and J,Ochsendorf, Material quantities and embodied carbon dioxide in structures, *ICE Proceedings*, August 2015.

<sup>38</sup> Lasvaux.S, Habert.G, Peuportier.B and J,Chevalier, Comparison of generic and product-specific Life Cycle Assessment database: application to construction materials used in building LCA studies, *International Journal for Life Cycle Assessment* (2015) 20:1473 - 1490

- Development of LCA tools and guidance: Notable projects include EEB Guide and ENSLIC<sup>39</sup>. The findings from the ENSLIC project are analysed in more detail in Section 3.3.7.

A brief synopsis of selected projects is provided in the following sections.

### 3.2.4.1 Supporting EPBD implementation

The main initiatives established to support EPBD implementation are the Concerted Action and BUILDUP initiatives, which are both funded by Intelligent Energy Europe<sup>40</sup>.

Concerted Action produces implementation reports that examine issues relating to Member State implementation of EPCs and, since the EPBD recast, the Nearly Zero-Energy Building (NZEB) requirement. Country reports enable the approach and lessons from each Member State to be compared and contrasted.

New projects such as ZEBRA 2020<sup>41</sup> are now being taken forward under Intelligent Energy Europe which seek to support implementation of the NZEB requirement. ZEBRA 2020 involves partners from seventeen Member States. It aims to '*deliver recommendations and strategies that accelerate the market uptake of nZEBs*' taking account of local contexts.

### 3.2.4.2 Addressing the gap between design and actual performance.

The ASIEPI (Assessment and Improvement of the EPBD Impact (for new buildings and building renovation) project<sup>42</sup> was funded by the Intelligent Energy programme and focussed on a number of technical issues relating to EPBD implementation. These included air tightness and thermal bridging associated with building fabrics.

Recommendations from ASIEPI on construction quality included an improved focus on the assessment of thermal bridges and air tightness during design and building permitting, together with a focus on execution quality, for example, by making the measurement of air tightness compulsory.

The QUALICHeCK project has brought together partners from nine European countries to share experience on the link between quality aspects and EPC compliance<sup>43</sup>. A comparison of EPC compliance between the different partners highlighted the potential for significant variance between calculated and measured performance, as well as between simplified and detailed calculation methods. Possible types of non-compliance within the process of issuing EPCs are illustrated in Figure 3.7. Overall the project has highlighted high EPC non-compliance rates, mainly relating to the quality of input data, and construction quality problems as requiring further attention.

The PERFORMER project aims to reduce the gap between design and actual performance<sup>44</sup>. It takes a different approach from ASIEPI and QUALICHeCK by focussing on the potential role of energy monitoring technologies for completed building projects. The monitoring of a number of demonstration buildings is currently still ongoing.

<sup>39</sup> ENSLIC Building, *Energy Saving through promotion of Life Cycle analysis in Building*, Intelligent Energy Europe, <https://ec.europa.eu/energy/intelligent/projects/en/projects/enslic-building>

<sup>40</sup> Concerted Action EPD (2016) *Implementing the Energy Performance of Buildings Directive*, Intelligent Energy Europe programme

<sup>41</sup> ZEBRA 2020, *Nearly Zero-Energy Building Strategy 2020*, <http://zebra2020.eu/>

<sup>42</sup> ASIEPI, *The final recommendations of the ASIEPI project: How to make EPB-regulations more effective?*, Summary final report, 31st March 2010

<sup>43</sup> QUALICHeCK (2016) *Improving the compliance of Energy Performance Certificates and the quality of building works*, <http://qualicheck-platform.eu/results/reports/>

<sup>44</sup> PERFORMER (Portable, Exhaustive, Reliable, Flexible and Optimized approach to Monitoring and Evaluation of building energy performance), <http://performer-project.eu/>

### 3.2.4.3 LCA tools and guidance

The EeBGuide project <sup>45</sup> sought to provide a common methodology and rules on how to carry out an LCA at building and product level. This was with the overarching aim of improving reliability and comparability of results. The guidance makes reference to both the EU ILCD Handbook and CEN/TC 350 standards. The project was co-ordinated by Fraunhofer IBP with the involvement of PE INTERNATIONAL, CSTB, ESCI and BRE. The guidance may therefore provide a useful reference point for performance indicators based on LCA methodologies.

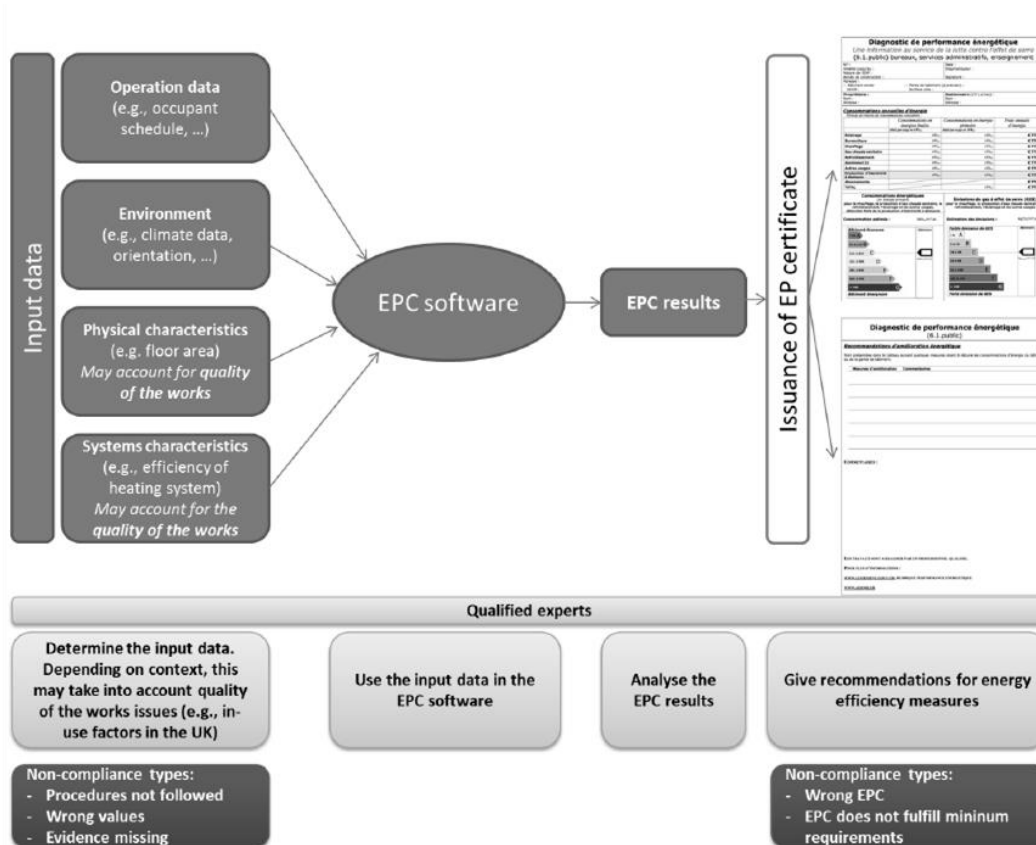


Figure 3.7 Steps in the process of issuing EPCs and possible types of non-compliance

Source: QUALICHeCK (2016)

### 3.2.5 Standards and harmonisation initiatives

#### 3.2.5.1 EN ISO 15603 as the basis for National Calculation Methods

The standard EN ISO 15603 was mandated to support implementation of the EPBD <sup>46</sup>. It forms part of a series of standards that were intended to support harmonisation of the National Calculation Methodologies (NCMs) for assessment of the overall energy use of a building.

Under CEN Mandate M/480 The EN 15603 standard, together with the suite of supporting standards such as EN 50216, are currently being comprehensively

<sup>45</sup> EeB Guide Project, *Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative*, Seventh Framework Programme, <http://www.eebguide.eu/>

<sup>46</sup> EN 15603, *Energy performance of buildings - Overall energy use and definition of energy ratings*, January 2008, Comité Européen de normalisation (CEN)

updated. EN ISO 15603 is anticipated to be superseded in 2016 by the CEN ISO/TR 52000, which will introduce an informative set of proposed indicators for the assessment of nearly Zero-Energy Buildings (nZEB).

EN ISO 15603 is applicable to both new and renovated buildings. It provides a general framework for the assessment of overall energy use of a building, and the calculation of 'weighted' energy ratings in terms of primary energy, CO<sub>2</sub> emissions or parameters defined by national energy policy. The system boundary may be an apartment or whole building. The weightings for primary energy and CO<sub>2</sub> shall be provided in an annex of the NCM.

The standard makes an important distinction between a calculated and measured energy rating, a distinction which is developed further in the new prEN 52000 series (see Table 3.2). It emphasises that the two cannot be directly compared, but that they can be used *'to assess the cumulative effects of actual construction, systems and operating conditions versus standard ones and the contribution of energy uses not included in the calculated energy rating'*.

This becomes an issue when seeking to compare calculated design performance with occupied operational performance. Two options would need to be considered in order to address the issue of comparability:

- sub-metering shall be installed that enables those delivered energy uses specified in the calculation method to be compared or,
- a tailored rating can be calculated which includes an estimate for those *'other uses of energy'*.

According to EN 15603 generic data can be provided at national level but in the absence of this, the standard provides in Annex C generic data for residential appliance and office equipment electricity use. This data is noted as having a high degree of variability, with a confidence interval of 50%.

In the draft prEN 52000 tailored ratings are developed further in order to reflect the distinct characteristics of each building being assessed – for example, actual data representative of the as-built construction, local climate and anticipated occupancy. Generic data is not currently anticipated to be provided as in EN 15603, with reference in the calculation method instead made to non-EPB energy uses.

*Table 3.2 Types of energy rating as defined by prEN ISO 52000-1*

Assessment type	Sub-type	Input data			Utility or purpose
		Use	Climate	Building	
Calculated (asset)	Design	Standard	Standard	Design	Building permit, certificate under conditions
	As built	Standard	Standard	Actual	Energy Performance Certificate, regulation
	Actual	Actual	Actual	Actual	Validation
	Tailored	Depending on purpose			Optimisation, validation, retrofit planning, energy audit
Measured (operational)	Actual	Actual	Actual	Actual	Monitoring
	Climate corrected	Actual	Corrected to standard	Actual	Monitoring or energy audit

	Use corrected	Corrected to standard	Actual	Actual	Monitoring
	Standard	Corrected to standard	Corrected to standard	Actual	Energy performance certificate, regulation

Source: ISO and CEN (2016)

Reporting frameworks for calculated and measured energy use are provided. For calculated energy use, reporting is divided into heating, cooling, domestic hot water, ventilation and lighting. For measured energy use reporting into energy delivered, energy exported and renewable energy generated on-site.

The standard does not make a clear distinction between so-called 'steady state' calculations (made on an annual or monthly basis) and 'dynamic' simulations (made on a daily or hourly basis) of the performance of buildings, referring only to the use of annual average values or to the division of a year into calculation steps (e.g. by the month, day or hour). The EPBD (recast) refers only to the need to reflect the heating or cooling seasons.

### 3.2.5.2 Advanced simulation methods under EN ISO 13970

A clearer set of definitions for the different types of calculation methodologies that may be used are provided by EN ISO 13790<sup>47</sup>, which is a supporting standard for EN 15603. This standard differentiates between two main methodologies:

- quasi-steady-state methods, calculating energy performance over one month or a whole season;
- dynamic methods, calculating energy performance over shorter time periods (typically one hour) and taking into account the thermal inertia of the building on a daily basis.

The standard provides a monthly quasi-steady state method, as well as simple and detailed dynamic methods.

An assessment period of at least three years with similar patterns of occupation is recommended and, moreover, that the first two years of occupation for a new building are invalid – an important consideration for Post Occupancy Evaluations. Assessment periods of less than three years require a correction for the local weather conditions.

As was noted in relation to EN 15603, this standard is similarly undergoing comprehensive updating and is planned to be superseded by prEN 50216.

### 3.2.5.3 Development of the common EU Voluntary Certification Scheme

As was introduced in section 3.2.5.3, a common EU Voluntary Certification Scheme (EVCS) for non-residential buildings is currently under development. A key driver for the EVCS is cited as the need for a common basis for the comparison of performance across the EU.

In particular, investors claim that they require greater certainty and standardisation in order to place a market value on buildings with an improved energy performance. This driver for the EVCS is explored further under macro-objective 6 (see Chapter 7).

Following consultations with stakeholders and Member States, this EVCS scheme will be founded on the prEN 52000-1 standard as its default option for the calculation and rating of energy performance of buildings. The EVCS will be

<sup>47</sup> EN ISO 13790, *Energy performance of buildings - Calculation of energy use for space heating and cooling*, Second edition, March 2008, Comité Européen de normalisation (CEN)

supported by a European Commission Implementing Regulation. This Regulation is anticipated to refer to a model ('default') energy label reporting format.

Based on material presented at the second project workshop held in Paris on the 21<sup>st</sup> April 2016 and the final project workshop held in Brussels on the 6<sup>th</sup> June 2016, the main current features of the proposed EVCS scheme are also anticipated to be as follows:

- Accreditation of assessors according to EN ISO 17024;
- Use of an hourly calculation interval and therefore a dynamic energy simulation;
- The same methodology for both new and existing buildings;
- Use of a variable value reference building based on cost optimal performance in 2012 to benchmark the EPC rating;
- Use of climate data that will be provided by the Joint Research Centre;
- Use of default values provided by the EN ISO standards if specific data is not available.

The main performance indicator to report on will be 'non-renewable primary energy balance' in kWh/m<sup>2</sup>.yr, with the possibility of also reporting on total primary energy, final energy and CO<sub>2</sub> emissions.

It is considered that other related performance indicators could be considered at a later point in time, once the market uptake of the EVCS has reached a certain level and experience is available.

### **3.3 Findings from investigation of the selected field study clusters**

The macro-objective 1 field studies consist of seven clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- ALTO offices – new-build and residential (France and Luxembourg): Operational energy use
- ALTO residential – MacDonald masterplan (France): Operational energy use
- MacDonald residential masterplan (Paris, France): Operational energy use
- ECO-Life: Operational energy use
- Skanska Group: Operational energy use and carbon footprinting
- Green Building Council Finland, Building Performance Indicator pilots: Design and measured energy use, carbon footprinting
- ENSLIC (ENergy Saving through promotion of Life Cycle assessment in buildings): Life cycle embodied CO<sub>2</sub> equivalent emissions

For each cluster, the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

#### **3.3.1 Cluster 1: ALTO offices – new-build**

##### **3.3.1.1 Translation of the macro-objective into actions and improvements by buildings in the cluster**

The performance targeted differs for each certification scheme (HQE, BREEAM, LEED, DGNB) and the year of registration. The following improvement options were identified:

- 1. Optimisation of the thermal envelope*

The goal of this improvement option is to reduce the building energy demand. Local regulation serves as the main point of reference. This improvement is achieved using different calculation methodologies in the different buildings:

- ZENORA: French Thermal Regulation of 2005 (RT 2005)  
"Ubat" represents the (average) heat loss of a building by transmission through the walls (including thermal bridges) and windows expressed in  $W/m^2/K$ . The lower the Ubat, the better the thermal performance of the building envelope.
- LA MARSEILLAISE: French Thermal Regulation of 2012 (RT 2012)  
"Bbio factor" is a dimensionless number expressed by a number of points calculated using the following relationship:  
 $Bbio = 2 \times (\text{Heating demand} + \text{Cooling demand}) + 5 \times (\text{Artificial lighting needs})$  in which heating, cooling and lighting demand of the building, are calculated by an hourly dynamic simulation software. Energy consumption of ventilation system and lighting facilities are based on default values included in the software.
- CBKII: Thermal Regulation from Luxembourg. The "wärmeschutzklasse" ( $KWh/m^2 \cdot year$ ) is linked to the German standard DIN 18599-2 and characterises the energy demand of a building zone for heating.

## 2. Reduction of energy consumption

- HQE: Reduce building primary energy consumption  $Cep < Cep$  reference (calculation from RT 2005 or RT2012)<sup>48</sup>
- BREEAM: Reduction of 37% as minimum compared to  $Cep$  to get credits required on the project (calculation from RT 2005 or energy performance regulation in Luxembourg)
- BBC Effinergie<sup>49</sup> :  $Cep < Creference - 40\%$  (calculation from RT 2005)
- LEED: Minimum Energy Performance Option 1: 10% improvement as minimum in the proposed building performance rating compared with the baseline building performance rating (calculation from ASHRAE 90,1-2007 Appendix G methodology)
- DGNB:
  - o Reduction of the building final energy consumption due to heating, cooling, lighting, hot water, ventilation & auxiliary, refrigeration of computer rooms & parking lighting, without kitchen process, and relative to Net Floor Area (NFA) (in accordance with DIN 277 standard)
  - o Reduction of primary energy consumption due to heating, cooling, lighting, hot water, ventilation & auxiliary, refrigeration of computer rooms & parking lighting, without kitchen process, and relative to NFA surface (in accordance with DIN 277 standard):  $85'025 m^2 NFA$

## 3. Reduction of CO<sub>2</sub> emissions

HQE: Reduction of 30% compared to HQE reference Project. To calculate the operational carbon emissions, primary energy consumption is multiplied by conversion factors provided by CERTIVEA (based on ADEME data).

## 4. Encourage local energy production from renewable sources

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<sup>48</sup> Cep: Conventional energy consumption of a building for heating, cooling, domestic hot water, electricity for pumps and fans, and lighting facilities are expressed in  $kWh/m^2 / year$  in primary energy

<sup>49</sup> BBC-Effinergie is a French certification for low energy buildings:  
<http://www.effinergie.org/web/index.php/282-english>

Local Low Zero Carbon (LZC) energy technologies have been installed on ZENORA and CBKII in line with recommendations of a feasibility study led by an energy specialist and this method of supply results in more than 15% reduction in the building's CO<sub>2</sub> emissions (not achieved in the project but a feasibility study has been conducted)

Furthermore, in the La Marseillaise project, a percentage of the total energy consumption is covered by on site renewable energy production. Urban district network linked to marine geothermal energy is used in the project and as a result the percentage is  $\geq 1\%$  than required by LEED certification scheme. Calculation are conducted with commercial dynamic simulation software using ASHRAE 90,1-2007 Appendix G methodology.

### **3.3.1.2 How performance improvements were measured**

*Potential indicators identified:*

- Operational carbon [kg CO<sub>2</sub>e/m<sup>2</sup>.year]
- Primary energy consumption [kWh/m<sup>2</sup>.year], [%]
- Reduction of energy consumption [%]

*Supporting indicators:*

- Proportion of energy demand covered by renewable energy production [%]
- Reduction of carbon emissions as a result of renewable energy production [%]
- Thermal insulation level of the building [W/m<sup>2</sup>.K]
- Air Tightness (only for ZENORA and this was not an initial goal – measure has been conducted by the client at end of works in order to integrate the result in the energy modelling calculation)

### **3.3.1.3 Implementation experience of practitioners involved with delivery of the improvements**

The three projects tried to reach high performance on several certification schemes. From ALTO's experience, achieving those goals are often linked to the ambition of achieving a high score related to energy performance.

Conventional energy performance calculation tools (according to local regulation) have been used. LA MARSEILLAISE (LEED) and CBKII (DGNB) required dynamic thermal modelling and new knowledge on new requirements for the team.

In the case of CBK II, the designers and contractors were not familiar with DGNB, as the version used was a pilot version. Other certification schemes (such as HQE, BREEAM) are more common in France. LEED is not well known by French designers but the methodologies and tools are easily available and well-explained.

Project specific lessons learned are:

ZENORA – The client was really engaged on this project to set ambitious environmental targets which was a major incentive to reach high certification levels and environmental performance.

CBKII – The pilot version of DGNB proved to be difficult for the design team: they were not always familiar with the different methodologies and units and the differences with the indicators and methods used (for instance, for local energy calculations) was sometimes confusing and difficult to understand for the design team. Furthermore, a general contractor could have been of great value for the project. Separated lots created difficulties regarding the certification process.



LA MARSEILLAISE - Specific presentations to the investors are done especially to justify achievement of energy goals. This helps the team in taking decisions and proposing improvement till the final achievement. Working with the investor is really benefic and we hope it will implies as less modifications as possible during works on energy aspects.

### **3.3.2 Cluster 2: ALTO offices – renovation**

#### **3.3.2.1 Translation of the macro-objective into actions and improvements by buildings in the cluster**

The performance targeted differs for each certification scheme (HQE, BREEAM, LEED, DGNB) and the year of registration.

Following improvement options were identified:

*1. Optimisation of the thermal envelop*

The goal of this improvement option is to reduce building energy needs. Reference is made to local regulation:

- RT EXISTANT using commercial steady-state energy simulations (e.g. CLIMAWIN)

*2. Reduction of energy consumption*

- RT EXISTANT using commercial steady-state energy simulations (e.g. CLIMAWIN)
  - o Local regulation  $C_{ep} < C_{ep}$  reference
  - o BBC Effinergie renovation  $C_{ep} < C_{ref} - 40\%$
  - o EULER and MEDERIC: Reduction of 37% as minimum compared to  $C_{ep}$  reference (calculation from RT 2005)
  - o EULER: LEED Minimum Energy Performance Option 1: 10% improvement as minimum in the proposed building performance rating compared with the baseline building performance rating (calculation from ASHRAE 90,1-2007 Appendix G methodology)

*3. Reduction of CO<sub>2</sub> emissions*

HQE: Calculation of CO<sub>2</sub> emissions. To calculate the operational carbon emissions, primary energy consumption is multiplied by conversion factors provided by CERTIVEA<sup>50</sup> (based on ADEME<sup>51</sup> data)

*4. Encouraging local energy generation from renewable sources*

A local Low Zero Carbon (LZC) energy technology – solar thermal collectors – has been installed on EULER in line with recommendations of a feasibility study conducted by an energy specialist and this method of supply results in less than 10% reduction in the building's CO<sub>2</sub> emissions (not achieved in the project but the study has been conducted, as a result, all BREEAM credits have not been awarded).

The same study has been done for the Mederick project but no LZC technology has been identified as more interesting for the project other than a gas boiler, combined with PV panels.

Laffite Lafayette did not implement any LZC energy technology because of local boundary conditions. (architectural conservation of roofs and volume)

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<sup>50</sup> CERTIVEA is the certification body of HQE in France and is affiliated with CSTB

<sup>51</sup> ADEME is the French Environmental Agency

### 3.3.2.2 How performance improvements were measured

*Potential indicators identified:*

- Operational carbon [kg CO<sub>2</sub>e/m<sup>2</sup>.year]
- Primary energy consumption [kWh/m<sup>2</sup>.year], [%]
- Reduction of energy consumption [%]

*Supporting indicators:*

- Proportion of energy demand covered by renewable energy production [%]
- Net energy demand for cooling [kWh/m<sup>2</sup>.year]
- Thermal insulation level of the building [W/m<sup>2</sup>.K]

### 3.3.2.3 Implementation experience of practitioners involved with delivery of the improvements

The indicators and associated methodologies except the ones associated with LEED certification were accessible and easy to use for each member of the team, as most of the energy performance requirements directly relate to the local regulation. LEED is not well known by French designers but methodologies and tools are available and explained.

The main challenge of the refurbishment projects was to make a compromise between the conservation of the architectural value (which was a mandatory aspect in some case) and achieving a high energy performance.

Project specific lessons learned are:

EULER: The client gave higher priority to indoor air quality instead of energy performance (which resulted in higher ventilation rates). Nevertheless, the related energy label has been achieved even with this decision.

LAFFITE LAFAYETTE :The certification ambitions have been decided relatively late in the process. As a result, associated indicators and methodologies were not well known by the client but he was aware of the fact that this would provide a higher market value. During construction, the destination of a number of spaces that were originally initially designed as offices were changed to other uses such as sports areas, cafeterias and conference rooms, which implied a risk in achieving the energy performance values.

MEDERIC: After completion of the construction works, the building was not entirely occupied, as a result, the client has begun a BREEAM In-Use certification.

## 3.3.3 Cluster 3: MacDonald masterplan (Paris, France)

### 3.3.3.1 Background and context to selection of the cluster

Boulevard Mac Donald is an urban redevelopment of about 600 m long (a rehabilitation of the old warehouses Macdonald, realised in the north of Paris, France. It consists of 15 multi-family buildings. A kindergarten has been integrated into a building and shops located on the ground floor. A part of the rehabilitation has integrated offices and a school program, but this part is not included in the analysis. ALTO Ingénierie was environmental consultant of all the 15 building units. The buildings had to achieve the following certifications: "*Habitat & Environment (H&E)*"<sup>52</sup> and "*Bâtiment Basse Energie (BBC)*"<sup>53</sup>.

<sup>52</sup> Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

Table 3.3 Boulevard Mac Donald masterplan, schedule of buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
N5	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	44 apartment units – 3 571m <sup>2</sup> SHON	In-use
N6	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	60 apartment units – 4 544m <sup>2</sup> SHON	In-use
S6	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	43 apartment units – 3 749 m <sup>2</sup> SHON	In-use
S7	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	82 apartment units – 7 355m <sup>2</sup> SHON	In-use
E1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	147 apartment units – 4 174m <sup>2</sup> SHON	In-use
N1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	45 apartment units – 5 041m <sup>2</sup> SHON	In-use
N2	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	90 apartment units – 5 905m <sup>2</sup> SHON	In-use
S1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	50 apartment units – 3 558m <sup>2</sup> SHON	In-use
S2	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	138 apartment units – 8 021m <sup>2</sup> SHON	In-use
O1	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	78 apartment units – 5 910m <sup>2</sup> SHON	In-use
N3	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	84 apartment units – 6 859m <sup>2</sup> SHON	In-use
N4	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	61 apartment units – 4 727m <sup>2</sup> SHON	In-use
S3	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	128 apartment units – 3 458m <sup>2</sup> SHON	In-use
S4	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	33 apartment units – 2 675m <sup>2</sup> SHON	In-use
S5	Central-Europe, Paris (FR)	Residential: Apartment block	New-build	42 apartment units – 3 279m <sup>2</sup> SHON	In-use

<sup>53</sup> BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

### 3.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The following improvement options were identified:

- *Optimisation of the thermal envelope:* Masterplan requirements included targets on maximum U values of the building components, minimum % of glazed surface per orientation and thermal bridges requirements.
- *Reduction of energy consumption:* The masterplan requirements implied BBC Label Effinergie of each building: Cep < 65 kWh/m<sup>2</sup>.year and Air tightness value <1m<sup>3</sup>/(h.m<sup>2</sup>)

The Cep is derived from the French energy regulation (Cep < Cep reference)<sup>54</sup>.

Air tightness requirements and energy performance targets are linked to the BBC Effinergie energy label. This is a voluntary label for low energy buildings in France, verified by a third party. The label is accompanied by a protocol (NF EN 13 829 and Manual GA P 50-784).

Finally, requirements regarding Low Zero Carbon (LZC) energy sources were defined on the masterplan as well:

- 25% of total energy consumptions covered by renewable energy
- 30% of the energy consumption covered by renewable energy for domestic hot water consumption

### 3.3.3.3 How performance improvements were measured

*Potential indicators identified:*

- Total primary energy consumption [kWh/m<sup>2</sup>.year]
- Reduction of energy consumption [%]

*Supporting indicators:*

- Air tightness [m<sup>3</sup>/m<sup>2</sup>.h]

### 3.3.3.4 Implementation experience of practitioners involved with delivery of the improvements

The targets required by the masterplan were not easy to combine with the architectural concepts.

A specific expertise – steady state calculation methodology in line with French Thermal Regulation 2005 – has been provided by ALTO Ingenierie regarding energy consumption optimization to answer to masterplan requirements and at the same time support the designers to find other design solutions to reach the initial targets as much as possible. The percentage of glazing per façades have not been reached as for example.

The integration of new buildings alongside the existing building of 600 metres long was a challenge regarding structure and air tightness. Compromises had to be found to ensure BBC labelling and conservation of the existing structure. As a result, light-weight façades have been preferred for some buildings to reduce as much as possible the building energy loads.

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<sup>54</sup> Cep: Primary energy consumption (Consumption Energie primaire), including energy consumption of a building for heating, cooling, domestic hot water, electricity for pumps and fans, and lighting facilities are expressed in kWh/m<sup>2</sup> /year in primary energy.

Data used for the energy certifications was derived from the as-built documents. Energy labelling and energy consumption requirements were already mandatory.

In the construction phase, the regular inspection of the quality of the construction works by the architect and responsible contractor is a very important task considering that some modifications could occur during construction phase.

The execution of quality assurance tests (by a third party, for example the environmental consultant) was useful to indicate during the construction works whether the final targets are realistic or there are specific issues to which extra attention should be paid.

Calculation of energy demand is required to get an energy label as BBC renovation. It is often done by the general contractor or HVAC contractor. This data is updated in the final energy demand calculations:

- in use ventilation rates verified via measurements by inspections
- results from duct air leakage tests according to NBN EN 12237
- performance of envelope's insulation and glazing
- air tightness measure results

In Paris, check from CERQUAL<sup>55</sup> - the HQE certification body – are getting stronger and stronger. This is not the case everywhere in France. As a result, quality between design and as built constructions may not be the same. This third part check is really important to ensure environmental performance.

### **3.3.4 Cluster 4: ECO-Life**

#### **3.3.4.1 Background and context to selection of the cluster**

The aim of the "ECO-Life project" is to demonstrate innovative integrated energy concepts across three countries in the EU where urban areas will be transformed into CO<sub>2</sub>-neutral communities. The three communities in the project are: Høje Taastrup in Denmark, Kortrijk in Belgium and Birstonas in Lithuania. The project is funded under the CONCERTO Initiative. The project was commissioned by the social housing company "Goedkope Woning" in Courtray. Both the apartment blocks and the single family houses are part of the social housing.

Phase 1 to 3 of the Venning District are monitored by the University of Ghent. Objective of the research project is to compare predicted performance to actual performance. Measurements on energy performance are executed such as blower door tests and thermographic analyses, in addition to monitoring of energy consumption and indoor environmental parameters (such as indoor temperature, humidity and CO<sub>2</sub> level).

The study provides information on how residents handle the new facilities, and which facilities they find more suitable than others. De Venning is the first large-scale research project in which different construction and ventilation systems are studied, tested and compared against each other. During and after the study, discussions will be held with the residents to find out how optimal results can be achieved.

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<sup>55</sup> CERQUAL is the certification body in France for the BBC label

Table 3.4 Eco-life masterplan, schedule of buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
Zone 1a	Central-Europe, Courtray (BE)	Residential: apartment blocks	New-build	3 buildings (70 dwelling units)	In-use
Zone 1b	Central-Europe, Courtray (BE)	Residential: multi-family house	New-build	1 building (12 dwelling units)	In-use
Zone 2	Central-Europe, Courtray (BE)	Residential: terraced	New-build	64 dwellings	In-use
Zone 3	Central-Europe, Courtray (BE)	Residential: terraced	Renovation	50 dwellings	In-use
Block V	Central-Europe, Courtray (BE)	Residential: apartment block	Renovation	1 building (108 dwelling units)	Construction

Building age of the renovated buildings: Apartment block: 1970s; single-family houses: 1960s

### 3.3.4.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The measures implemented in this project include: thermal bridge free design, passive house windows, ventilation with heat recovery, improved insulation, airtight construction, low temperature heating and on-site renewables (e.g. PV panels). Theoretical calculation and measurement campaign are conducted by different actors involved in the project in order to assess the performance of these proposed measures.

The target of the ECO-Life project is to establish zero-carbon neighborhoods. Tighter E-level and K-level, comparing to Flemish EPBD standard, are set as the main targets for new and renovated buildings, being E25 – E30 and K15 for both new apartment and house while E30 – E37 and K20 for renovated houses. Besides, Belgian Passive House Requirement is also used as the general guideline during the building design stage for some specific targets, e.g. airtightness  $\leq n50 - 0.6/h$ .

Flemish EPBD tools are used to calculate the indicators. Furthermore, energy meters are installed in different levels in the district in order to measure and validate actual energy use while different quality assurance tests are conducted in different life cycle stages to verify actual building performance.

### 3.3.4.3 How performance improvements were measured

The main and supporting indicators are identified as follows:

- Carbon emission [tCO<sub>2</sub>e]
- Primary energy use [kWh/m<sup>2</sup>year] or [E-level]
- Net energy demand [kWh/m<sup>2</sup>year]
- Thermal insulation level [K-level]
- Airtightness [h<sup>-1</sup>] at 50 Pa

Primary energy use, carbon emission, net energy demand and thermal insulation level are output from Flemish EPBD tools, and airtightness is required according to passive house requirement. The scope of most studied indicators is building use stage while only that of thermal insulation level being construction stage.

The target of the ECO-Life project is to establish zero-carbon neighborhoods. This general target was translated into an unambiguous definition and a number of characteristics and requirements. In a zero-carbon neighborhood the energy use is covered or compensated by energy generated in the neighborhood from sustainable zero-carbon energy sources. The metric of the balance is CO<sub>2</sub>-equivalents and the balancing period is one year. This means that the net amount of CO<sub>2</sub>-equivalents released on a yearly basis should be zero.

At building level, the target is translated with flexibility, meaning that some buildings might perform better than the others, but the overall target remains the carbon neutral. Therefore, carbon emission is not evaluated at building level in this project, and it is calculated at the district level with taking into account the global energy balance between generation and consumption.

Net energy demand includes all energy demand for space heating, space cooling, domestic hot water, auxiliary energy and the energy demand for collective functions such as elevators and outdoor lighting in the entire neighborhood. Household electricity is not taken into account for energy demand, therefore the scope of operational primary energy use has a significant implication on the results, but it can be measured and verified with metering data.

Another additional finding is that the type of ventilation system has much larger impact on the difference in heating energy demand than the typology. To verify airtightness, the blower door test was repeated in selected dwellings before and after the occupation, and the results showed some deviations among these tests, however in general, the airtightness remains a "low" difference (not significant when considering the low airtightness level); and the high air leakage can be caused by small things, for instance, measurement equipment error, leakage from small holes, attic and ventilation openings, unclosed windows, aging etc. Different people conduct the measurements might be the reason of the difference between these tests.

Energy performance and insulation level are usually inherently linked together, and it is common to see that well insulated buildings theoretically perform better from energy perspective. In addition, it is also obvious that insulation level and airtightness are usually linked together, better building insulation usually means less air leakage and better airtightness. The trade-off between energy performance and thermal comfort is also identified in this field study. The net energy demand is constrained through requirements for comfort and indoor climate.

#### **3.3.4.4 Implementation experience of practitioners involved with delivery of the improvements**

The ambition of the Venning district in ECO-life is to be a zero carbon district. In reality, no CO<sub>2</sub> targets are set at building level and it is interpreted as net energy balance between generation and consumption at district level in the use phase. This reflects the EU ambition of 'near zero energy buildings', with the associated range of different definitions.

To validate the actual building performance, during the building use phase, actual energy consumption is measured and analyzed by researchers from the University of Ghent with the supports of clients and inhabitants. Designed energy demand are rather low, but the gap shows that energy demand varies strongly between the dwellings. The comparison between actual and design energy use for space heating and domestic hot water in Zone 1 are shown in Figure 3.8 below.

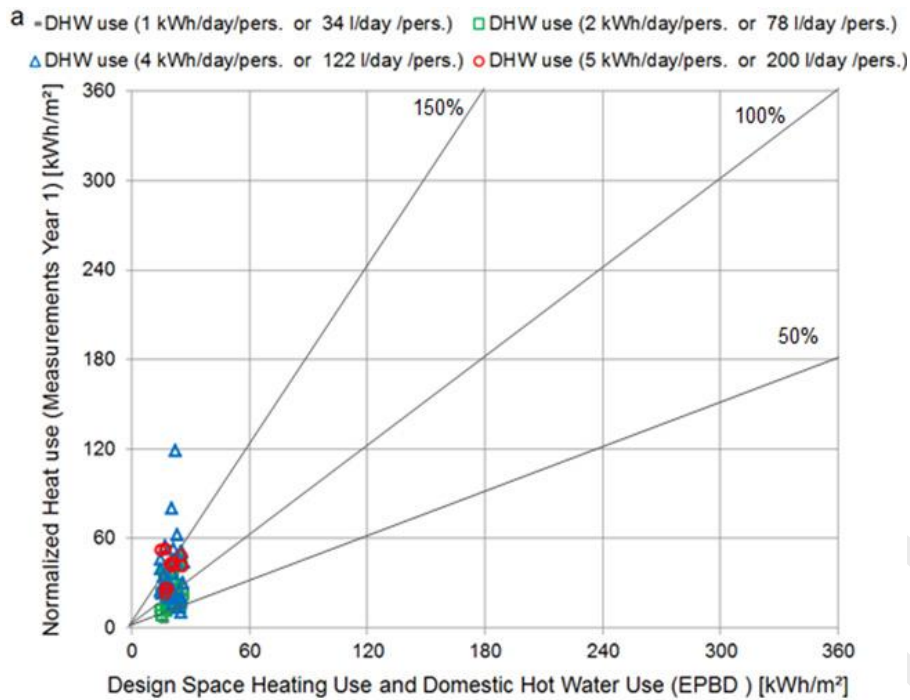


Figure 3.8a Design energy use for space heating and domestic hot water

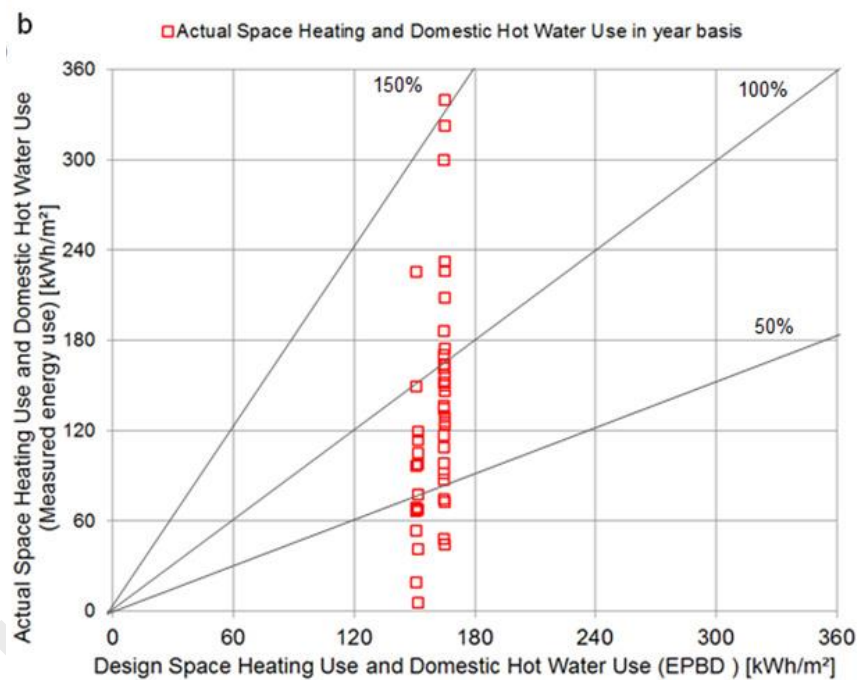


Figure 3.8b Actual energy use for space heating and domestic hot water

ECO-life provides useful information related to performance gaps as a result of user behavior, input data and modeling. The model and assumptions used to estimate the operational primary energy use of a new building, or the improvement potential of a refurbishment, can have a significant impact on the actual operational energy consumption. For instance, in EPBD tool, the results of E-level can alter by different default settings and primary energy conversion factors in static simulation model.

Furthermore, some countries, cities, refurbishment programmes and certification schemes have set stricter requirements for quality tests, for instance in this field



study, airtightness test is required for passive house certificate in Belgium. Last but not the least, certain indicators, such as airtightness, can be used to monitor the quality of construction, which can also be a significant factor in explaining any deviation between design and actual operational energy performance. Different tests are conducted in selected buildings, e.g. co-heating test and airtightness tests. However from the current experience of the researchers, and it can be sometimes difficult to execute valid practical tests due to the measurement error or other issues (hard to interpret the results).

### 3.3.2 Cluster 5: Skanska plc

#### 3.3.2.1 Background and context to selection of the cluster

Skanska is a private project development and construction group. Skanska is active in North America and Europe (in particular Northern Europe, Eastern Europe and the UK). In particular with regards to using carbon footprinting in the building practice, the Skanska Group have extensive experience in several EU Member States. The field study analysis draws upon Skanska's public database of pilot projects<sup>56</sup> and interviews with representatives from individual Business Units (BUs) in each country. The cluster of buildings analysed is presented in Table 3.5.

Carbon footprint assessments are an important component of Skanska's environmental strategy. The Skanska Group has defined a Green Strategic Indicator related to carbon emissions for its Business Units (BUs), i.e. the number of projects that have been submitted to a Preliminary Carbon Footprint <sup>57</sup>Error! Bookmark not defined. Skanska conducted 113 carbon footprints in 2015 to benchmark project carbon emissions and to help identify low-carbon project options, which can result in project carbon and financial savings.

Table 3.5 European buildings constructed by Skanska Group for which carbon footprinting has been carried out

Building	Climate zone, Location	Typology	Type	Scale	Stage
Skanska Finland HQ	Northern Europe, Helsinki (FI)	Office: medium-rise	New-build	8 storeys, 9.100 m <sup>2</sup>	In-use
Cold Harbour Lane	Central Europe, London (UK)	Residential: apartment block	New-build	2 buildings, 6 to 9 stories, 9.747 m <sup>2</sup> per building, 108 apartments	In-use
Sollallén townhouses	Northern-Europe, Växjö (SE)	Residential: terraced, semi-detached	New-build	21 dwellings (ranging from 79 m <sup>2</sup> to 91 m <sup>2</sup> )	In-use
Väla Gård	Northern Europe, Helsingborg (DK)	Office, medium rise	New-build	1.777 m <sup>2</sup>	In-use
Bassängkajen	Northern Europe, Malmö (SE)	Office, medium-rise	New-build	8.500 m <sup>2</sup> (phase 1) 7.800 m <sup>2</sup> (phase 2)	In-use
Powerhouse Kjørbo	Northern Europe,	Office, low- and medium-	Renovation	5.180 m <sup>2</sup> (total); 2 buildings	In-use

<sup>56</sup>Skanska (2012) Aspects of sustainability – case studies [online], available at <http://www.skanska-sustainability-case-studies.com/> [20/5/2016]

<sup>57</sup>Skanska (2015) Carbon [online], available at: <http://group.skanska.com/sustainability/environmental-responsibility/carbon/> [20/5/2016]

	Sandvika (NO)	rise			
Atrium 1	Central Europe, Warsaw (PL)	Office, high-rise	New-build	15 stories, 16.300 m <sup>2</sup> (office space)	In-use
Corso Court	Central Europe, Prague (CZ)	Office, medium-rise	New-build	7 stories, 17.202 m <sup>2</sup> (office space)	In-use
Riverview	Central Europe, Prague (CZ)	Office, medium-rise	New-build	7 stories, 7.037 m <sup>2</sup> (office space)	In-use
City Green Court	Central Europe, Prague (CZ)	Office	New-build	8 stories, 16.300 m <sup>2</sup> (office space)	In-use
Open Garden	Central Europe, Brno (CZ)	Office	New-build, renovation	1.454 m <sup>2</sup> (re-furbished); 2.900 m <sup>2</sup> (new-build)	In-use
Green House	Central Europe, Budapest (HU)	Office medium-rise	New-build	8 stories, 17.900 m <sup>2</sup> (office space)	In-use

### 3.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The Skanska Group developed a strategic framework to define its environmental ambitions, the Skanska Color Palette <sup>58</sup>Error! Bookmark not defined. In this field study analysis, main focus is on carbon, one of the four key components of the Color Palette.

The starting point is *Vanilla*: compliance with current regulation, codes and standards. End ambition is *Deep Green*: Near zero carbon in construction, in the case of carbon. In between are three intermediate targets (the Skanska group uses the term *stepping stones*). In the case of carbon, these are:

1. perform a carbon footprint calculation;
2. 25% CO<sub>2</sub>-reduction;
3. 50% CO<sub>2</sub> reduction.

The Color Palette serves as an overall framework but has to be specified by each business unit. It does allow each business unit some flexibility in the sense that they can adapt its (both intermediate and end) targets according to the local and regional context.

The tools and methodologies used to perform the carbon footprint calculations, very much depend on the national or regional context. Skanska's BUs make use of other methodologies or databases for the carbon footprint calculations when available<sup>59</sup>. For instance:

- Skanska Norway uses the Norwegian government's carbon calculation tool (Klimagassregnskap<sup>60</sup>, (v1 was launched in 2007, current version is v5));
- Skanska Finland trialed the use of BIM (Building Information Modeling);

<sup>58</sup> Skanska (2016) *How we define green* [online], available at <http://group.skanska.com/sustainability/our-journey-to-deep-green/how-we-define-green/> [20/5/2016]

<sup>59</sup> Skanska (2012) *Carbon footprint in construction – examples from Finland, Sweden, Norway, UK and US* [online], available at <http://www.skanska-sustainability-case-studies.com/index.php/latest-case-studies/item/140-carbon-footprinting-in-construction> [20/05/2016]

<sup>60</sup> Klimagassregnskap (2016) *Klimagassregnskap*, Available at <http://www.klimagassregnskap.no/> [20/5/2016]

- The Swedish BU uses the ECO2-tool, which is based on the LCA/LCC tool Anavitor, developed by the Swedish Environmental Research Institute (IVL)<sup>61</sup>.

Furthermore, in the case that Skanska operates as the contractor, the targets, tools, databases and boundary conditions (scope, assumptions) regarding carbon footprinting depend on the client's ambitions, and the nature of the building. If there are no specific requirements, Skanska uses their own developed, group-wide project carbon footprinting tool, which is a standardized, simplified tool linked to other tools such as cost estimation programs.

The main value of the carbon footprint tool in practice is for optimisation purposes. A carbon footprint is typically conducted in two stages, depending on the stage of entry: Ideally, in a first step, a preliminary carbon footprint is made, based on the information provided from the client (in practice, for the major building components: steel and concrete structure; windows). Then, in a second step, the final carbon footprint is calculated in or at the end of the construction phase.

Selected BUs make more advanced use of carbon footprint to really support the decision-making in design phase, starting with identifying opportunities for improvement ("hot spots") after the first step, which leads to the optimization of building components and/or construction process, for instance leaner design of the load bearing structures (in terms of form and dimensions of elements) as they have significant impact<sup>62</sup>. However, several BUs remarked that the reduction of carbon emissions is rarely the main driver. Cost-saving measures or construction process optimisation tend to be more decisive.

### 3.3.2.3 How performance improvements were measured

Key indicators identified regarding carbon emissions are:

- Embodied carbon [tCO<sub>2</sub>e or normalized kgCO<sub>2</sub>e/m<sup>2</sup>]
- Operational carbon [kgCO<sub>2</sub>e/m<sup>2</sup>/yr]
- Carbon footprint [tCO<sub>2</sub>e or normalized kgCO<sub>2</sub>e/m<sup>2</sup>]

Functional units can differ, more specifically the assumed lifespan. For instance, Skanska Norway reported a common lifespan of 60 years but this can be customized, according to the building program (for instance: museums). Skanska Sweden reported a default standard economic life span of 50 years for a building, but this can vary for each project.

Likewise, the life cycle stages and scope covered in a building's carbon footprint can differ as well, depending on the objectives of the study and data limitations. For instance, carbon related to operation and demolition may be excluded when Skanska has a limited ability to influence these phases. Skanska Norway reported that this largely depend on the project and/or client. Skanska Sweden reported that production and construction are always considered but that Use phase and End of Life stages are included depending on the project and the clients requirements. Benefits and loads beyond the project boundaries are not considered in the case of Skanska Sweden.

Finally, Skanska Hungary and Poland reported that their carbon footprint calculations prioritise the building components with the most significant contribution to the (embodied) carbon emissions: superstructure, substructure, fit-out, façade (in particular windows) (including transport and energy use during construction). This also relates to data availability (for instance, data on common building components such as steel and concrete structures are more easy to obtain).

<sup>61</sup> Anavitor (2016) *Anavitor* [online], available at <http://www.anavitor.se/> [20/5/2016]

<sup>62</sup> Van de Vyver I. and Larsson G. (2016). *Use of carbon footprint in Skanska SE*

Regarding data requirements, a distinction can be made between (carbon) emission data and material quantities. Carbon emission data (for the ECO2-tool used by the Skanska group) is obtained from "Inventory of Carbon & Energy (ICE) Version 1.6", "Defra(2007), GHG 2009 Protocol Tool", "ecoinvent 1.3" databases, and World resources Institute (2009) GHG Protocol Tool. Calibration with local conditions might be necessary [SKANSKA CZ]. SKANSKA NO reported that this varies, depending on the client: data from EPDs is used or calculated coefficients from Simapro using various LCIA-methods ( Ecoinvent) or generic data from the database of the national web based tool (klimagasregnskap.no). Skanska Sweden reported that emission data is provided by Swedish Environmental Research Institute IVL.

Material quantities are in practice obtained from a combination of sources, which include cost estimations, Bill of Quantities, BIM, discussions with designers and contractors, and literature. For as-built documentation, BIM-models are usually the most reliable source [interview with SKANSKA NO<sup>63</sup> and SKANSKA SE<sup>Error!</sup> Bookmark not defined.].

#### **3.3.2.4 Implementation experience of practitioners involved with delivery of the improvements**

Skanska Sweden reported that the (intermediate) targets of carbon footprint as specified in Skanska's Color Palette are very difficult to achieve. As a matter of fact, none of the Skanska building projects to date have been able to achieve the 25% CO<sub>2</sub>-reduction, although it has been achieved with infrastructure projects. Furthermore, cost-saving and process optimization happen to be the main drivers for the construction and construction process instead of the reduction of carbon emissions, although a carbon footprint calculation supports the identification of hot spots.

The Skanska group mainly uses the carbon footprint calculations for benchmarking purposes and each BUs seems to possess key reference projects to make comparisons with, as an addition to a group-wide database. However, it remains difficult to compare and benchmark among different projects since there are a lot of assumptions and system boundaries that may differ [interview with Skanska Sweden <sup>Error!</sup> Bookmark not defined.]. As some countries lack common guidelines or regulation concerning (embodied) carbon footprinting, carbon footprints calculated by different companies are very difficult to compare [interview with Skanska Czech Republic <sup>64</sup>].

Finally, interviews with the different BUs highlighted that carbon footprint calculations can be time consuming and skill-intensive. This could be addressed by coupling it with existing tools (especially Bill of Quantities (BoQ), BIM, REVIT to obtain material quantities) and further optimising the interaction between the carbon footprinting and these tools.

### **3.3.3 Cluster 3: Green Building Council Finland, Building Performance Indicator pilots**

#### **3.3.3.1 Background and context to selection of the cluster**

The Building Performance Indicators is an initiative of the Green Building Council Finland, in cooperation with actors in the real estate and construction industries. The indicators are based on the European CEN/TC 350 family of standards. The indicators are suitable for anyone working in the industry. Furthermore, they are open-source and publicly available on the website of GBCF. Currently, the GBCF's

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<sup>63</sup> Van de Vyver, I. and Fjeldheim, H. (2016). *Interview with Skanska NOR regarding carbon footprint*

<sup>64</sup> Van de Vyver, I. and Lhoták, P. (2016). *Interview with Skanska CZ regarding carbon footprint*

database contains 20 to 25 buildings (with the majority office buildings). The selected building are listed in the table 3.6.

The GBCF's eight Building Performance Indicators cover three of the six macro-objectives, more particular: Reduction of carbon emissions (B1), healthy and comfortable spaces (B4) and life cycle cost and value (B6). Macro-objective B1, Greenhouse gas emissions from building life cycle energy use, is highlighted in this summary, with focus on both aspects of "Operational carbon emissions" and "Embodied carbon emissions".

*Table 3.6 Buildings that have reported performance using the GBCF Building Performance Indicators*

<b>Building</b>	<b>Climate zone, Location</b>	<b>Typology</b>	<b>Type</b>	<b>Scale</b>	<b>Stage</b>
The Ministry of Environment	Northern-Europe, Finland	Office	Renovated	8.436 m <sup>2</sup> (GFA <sup>65</sup> )	design 2013/use 2015
Peab, Ultimate Business Park	Northern-Europe, Finland	Office	New-build	12.490 m <sup>2</sup> (GFA) / 550 persons	design 2014
Wood City, SRV	Northern-Europe, Finland	Office	New-build	12.800 m <sup>2</sup> (GFA)	Design 2015
The Ministry of Environment	Northern-Europe, Finland	Office	New-build	58.296 m <sup>2</sup> (GFA)	In-use 2013
Nokia-House 4	Northern-Europe, Finland	Office	New-build	6.407 m <sup>2</sup> (GFA)	In-use 2013
Quartetto	Northern-Europe, Finland	Office	New-build	8.040 m <sup>2</sup> (GFA)	In-use 2013
Säterinkatu	Northern-Europe, Finland	Office	New-build	30.270 m <sup>2</sup> (GFA)	In-use 2013
Pöyrytalo	Northern-Europe, Finland	Office	New-build	8.735 m <sup>2</sup> (GFA)	In-use 2013
Kathy / Skanska	Northern-Europe, Finland	Office	New-build	58.296 m <sup>2</sup> (GFA)	In-use 2013

### **3.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

The proposed improvement options are to reduce carbon emissions and energy consumption. The GBCF did not define specific targets for the Building Performance Indicators, but did provide publicly available background information on its website, including a comprehensive calculation guide and web-tool for each indicator.

The main standards applied in most of the studied cases are LCA standards EN-15978 and EN-15804, and National Building Code of Finland - section D3 (2012) "Energy management in buildings". Regulatory energy calculation tools, dynamic

<sup>65</sup> GFA: Gross Surface Area

thermal simulation tools are generally applied in some cases, while some other cross sector/sector specific tools are also used in different selected case studies.

### 3.3.3.3 How performance improvements were measured

*The main indicators relevant for macro objective B1 are identified as follows:*

- E-Value Indicator [kWh/m<sup>2</sup>year]
- Life-Cycle Carbon Footprint Indicator [kg CO<sub>2</sub>e/netto-m<sup>2</sup>/evaluating period]
- Operational Carbon Footprint Indicator [kg CO<sub>2</sub>e/heated cross-m<sup>2</sup>]
- Measured Energy Consumption Indicator [kWh/heated brm<sup>2</sup>]
- Baseload Demand Indicator [kW]

The E-value Indicator represents a building's calculated annual consumption of purchased energy, according to the heated net interior area and based on the standard use of the building type and weighted coefficients of the energy forms used. E-value is needed for building permits and statutory energy performance certificates. It can be used to optimize design solutions and it can be used in the retail and the renting of buildings.

Operational Carbon Footprint Indicator is calculated according to the Green House Gas (GHG) Protocol. Measured Energy Consumption Indicator measures the consumption of purchased energy in a property. Baseload Demand Indicator is defined as building's energy demand when it is not producing services for the occupants. To assess it, building needs to be equipped with a monitoring system that can measure at least the hourly electricity consumption. The baseload demand should be assessed based on a study period of at least one week.

### 3.3.3.4 Implementation experience of practitioners involved with delivery of the improvements

In general, the guides for conducting calculations for different indicators are very well-written and available online and calculation tools on website are also well-developed. Users without technical background can also follow the instruction and conduct the calculation. However, calculation of some indicators can be time-consuming, and it is also difficult to find paying customers who are willing to pay for the calculation of these indicators. Practical experience of conducting calculation on selected indicators are provided below <sup>66</sup>.

E-value is mandatory according to Finish building code. The same building can have several E-values, if the building has several purposes (e.g. office – business premises) and if these different operations cover more than 10% of the heated net interior area. However, in the Building Passport, only one E-value is presented, according to the principal purpose of the building.

The GBCF explicitly notes in its guidelines that, due to the weighted coefficients of different energy sources, the E-value indicator is not comparable with the measured energy consumption indicator. Also, the E-value indicator is normalised in all cases according to the climatic conditions in southern Finland, while the other indicators assess a building's performance in the climate conditions of the region it is located in.

To normalise measured energy consumption, it can be difficult to obtain the correct floor area, therefore, in some cases, only part of the building area is used in the calculation. The building metering system is a key component. These systems make it relatively easier to acquire this data, but it is also difficult to contact the right person and to have them circulate the correct data. This indicator is calculated in excel and the spreadsheet is provided by GBCF, which is

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<sup>66</sup> Van de Vyver I. and Melander-Ekström I. (2016). *Practical experience of Ramboll Finland in using the GBC Finland's Use phase Building Performance Indicators*

straightforward to enter information in online tool once the required data is available. The most time-consuming part is to get the needed data in a proper and usable format.

Operational carbon footprint is very much aligned with measured energy consumption, it requires not that much “extra work” from a practical perspective. In Finland, embodied carbon footprint is not very well recognized and widely accepted compared to energy consumption. People do not really understand why they should calculate it, how to calculate it and how to interpret the results. People are only interested in short-term indicators. EN 15978, part of BREEAM and LEED certificates, is the only motivation. To conclude, it is hard to motivate people to be interested in this abstract concept.

### 3.3.4 Cluster 4: ENSLIC (ENergy Saving through promotion of LIfe Cycle assessment in buildings)

#### 3.3.4.1 Background and context to selection of the cluster

ENSLIC (ENergy Saving through promotion of LIfe Cycle assessment in buildings) is an Intelligent Energy Europe (IEE) project<sup>67</sup>. Nine partners from as many countries (Austria, Netherlands, France, Spain, Germany, Hungary, Norway, Sweden, Bulgaria) were involved. The project coordinator was Fundación CIRCE - Centro de Investigación de Recursos y Consumos Energéticos – Spain.

The aim of the project was to promote the use of Life Cycle Assessment (LCA) techniques in design for new buildings and for refurbishment, in order to achieve an energy saving in the construction and operation of buildings. It started in 01/10/2007 and ended in 31/03/2010.

Table 3.7 EU buildings analysed as part of the ENSLIC project

Building	Climate zone, Location	Typology	Type	Scale	Stage
<b>CIR CS1</b>	South Europe - Zaragoza, Spain	Apartment block	Existing	5 floors - 7641 m <sup>2</sup>	In use
<b>CIR CS2</b>	South Europe - Zaragoza, Spain	Apartment block	Existing	7 floors - 8607 m <sup>2</sup>	In use
<b>CIR CS3</b>	South Europe - Zaragoza, Spain	Offices	Renovation	2 floors - 1700 m <sup>2</sup>	-
<b>ARM CS1</b>	South Europe - Formerie, France	Semi-detached houses	Existing	2 floors - 132 m <sup>2</sup>	In use
<b>ARM CS2</b>	South Europe - Montreuil, France	Apartment block	Existing	6 floors - 5124 m <sup>2</sup>	In use
<b>ARM CS3</b>	South Europe - France	Apartment block	Design	6 floors - 6600 m <sup>2</sup>	Design phase
<b>IFZ CS1</b>	Central Europe - Weiz, Austria	Semi-detached houses	Existing	2 floors - 113,7 m <sup>2</sup>	In use
<b>IFZ CS2</b>	Central Europe - Weiz, Austria	Offices	Existing	4 floors - 3068 m <sup>2</sup>	In use
<b>IFZ CS3</b>	Central Europe - Gutenberg, Austria	Semi-detached houses	Existing	3 floors - 202,4 m <sup>2</sup>	In use
<b>EMI CS1</b>	Central Europe - Budapest, Hungary	Apartment block	Existing	11 floors - 25138 m <sup>2</sup>	In use
<b>KTH CS1;</b>	North Europe -	Offices	Design	4 floors -	Design phase

<sup>67</sup> <https://ec.europa.eu/energy/intelligent/projects/en/projects/enslic-building>

	Gävle, Sweden			3314 m <sup>2</sup>	
<b>KTH CS2;</b>	North Europe - Sollentuna, Sweden	Offices	Design	4_6 floors - 10000 m <sup>2</sup>	Design phase
<b>CAL CS1</b>	Central Europe - Frankfurt a. M., Germany	Apartment block	Existing	9 floors - 2353 m <sup>2</sup>	In use
<b>CAL CS2</b>	Central Europe - Frankfurt a. M., Germany	Apartment block	Existing	3 floors - 2662 m <sup>2</sup>	In use
<b>CAL CS3</b>	Central Europe - Frankfurt a. M., Germany	Apartment block	Existing	4 floors - 1482 m <sup>2</sup>	In use
<b>ECO CS1</b>	Central Europe - Kollum, Netherlands	Detached house	Existing	3 floors - 170 m <sup>2</sup>	In use
<b>ECO CS2</b>	Central Europe - Nieuwegein, Netherlands	Offices	Design	92 floors - 16278 m <sup>2</sup>	Design, tendering

### 3.3.4.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

ENSLIC focussed on primary energy use and climate change potential indicators. The cases covered in ENSLIC are assessments of existing designs or buildings. Different purposes of LCA were tested. Performance improvements assessed were:

- environmental impact as a result of material choices;
- reduction of carbon emissions from life cycle perspective as a result of highly ambitious energy performance (passive building);
- comparison of different design choices for building components.

ENSLIC explored how to simplify LCA with the purpose of increasing the use of LCA in the building practice. Proposed simplifications are: limiting the number of life cycle stages to production (A1-A3) and operation (B1-B7); limiting the number of impact categories (for instance, only global warming potential); making use of BIM and CAD-software. ENSLIC developed an own methodology, more specifically a simplified excel-sheet, based on ISO 14040-14043. Full list of proposed simplifications <sup>68</sup>:

- Simplify the acquisition of building data by focusing on larger building elements, omit transport, etc.
- Simplify the inventory analysis by focusing on the most important substances that contribute to a certain impact category, omit the end of life of the building, only use generic emission data, etc.
- Simplify calculations by focusing on only a few impact categories.
- Reduce the time of building data acquisition by improved CAD applications.

ENSLIC distinguished three categories of LCA-tools, depending on the complexity<sup>68</sup>:

- Basic: Basic calculations in Excel sheets with simple input and output only covering one or a few environmental impacts. Little or no experience is needed.
- Medium: LCA calculations made with help of building tools such as Ecosoft, EcoEffect, Equer, Legep, Envest, Beat, etc. Some experience and training are required to use these tools.

<sup>68</sup> Malmqvist T., Glaumann M., Scarperllini S., Zabalza I., Aranda A., Llera E., Díaz S. (2010) *Life cycle assessment in buildings: the ENSLIC simplified method and guidelines*, *Energy* 36 (2011), 1900 - 1907



- Advanced: General and comprehensive LCA tools such as SimaPro, Gabi, etc. Much experience is needed to handle these software applications on a building level. These tools demand much training and profound understanding of LCA models and they might not even be suitable for application in early design phases.

The goal for the simplified tool developed in ENSLIC is to support the two lower levels, i.e. getting inexperienced people to first carry out simple LCAs and then try the buildings tools. Advanced LCA calculations are therefore not covered further in the ENSLIC project.

#### **3.3.4.3 How performance improvements were measured**

The LCA-calculations in ENSLIC focus on the following indicators: Global Warming Potential, primary energy consumption and energy demand.

*Key indicators:*

- Global Warming Potential [tons CO<sub>2</sub>e]
- Primary Energy Consumption [GJ]

*Supporting indicator:*

- Energy demand for heating, cooling, lighting or other uses [kWh/m<sup>2</sup>.year]

However, the life cycle stages, boundary conditions, functional units, vary considerably, depending on the country or practitioner. In the case of the functional unit, a default lifespan of 50 years is considered, but other assumptions ranging from 35 to 80 years are used as well.

Regarding the life cycle stages, the majority of the cases only include Production (A1-3) and Use stages (B1-B7). Selected cases made the comparison between the detailed (taking into account all four life cycle stages) and simplified LCA (only including production and use). As an illustration, distribution of GWP is as follows in case of CIR CS3: production 42,9%; construction 1,6%; use 51,4%; End-of-Life 3,3%.

The scope was limited to the building structure and envelope (in case of production stage) and to heating, cooling, domestic hot water and auxiliary energy consumption (in case of use stage), although there could be some variations in the cases, depending on the objective of the LCA.

As collected data are linked to LCA databases, other LCA-indicators such as resource depletion or water depletion can be assessed depending on the selected evaluation method. In addition, the LCA can be coupled with Life Cycle Cost analysis. When elaborating bill of materials, data regarding value and costs can be collected simultaneously. Costs of maintenance, energy, waste management, water and cleaning can also be collected.

#### **3.3.4.4 Implementation experience of practitioners involved with delivery of the improvements**

While the goal of the project was to facilitate the use of LCA in practice, it is still unclear if the project succeeded in its objective, as all the cases were hypothetical exercises. No real-life pilot in the context of the building process was included. This is an aspect that should be taken into account when interpreting the findings of the ENSLIC study.

That said, a wide range of buildings were assessed, using local tools and databases. While lessons can be derived regarding the proportion of embodied/operational energy or carbon and the division among building aspects, the results are rather difficult to compare, as each assessor has their own purposes, tools, boundary conditions and assumptions for the LCA. The results

are thus very much dependent on the party who conducted the calculations. This highlights the need for additional guidelines to further complement common methodology.

The ENSLIC guidelines are directed at professionals working in the early design phases of building development or refurbishment projects who want to achieve energy savings and environmental improvements with regard to the entire lifetime of the building.

Architects and other consultants are the main target group, since they are the professionals involved who can perform an LCA assessment. Clients such as property developers and urban planners are also targeted, since these groups can demand better buildings and associated assessments to prove this.

### **3.4 Findings from the operational experience of selected assessment and reporting schemes**

#### **3.4.1 Assessment and reporting schemes**

In this section, a summary of the main themes and findings that have emerged from a detailed cross-check of relevant criteria from five major certification schemes – BREEAM UK, HQE, DGNB, LEED and VERDE (based on SB Tool) - together with associated interviews are presented.

Reference is also made to the criteria of a number of residential-only schemes – Home Performance Index (Ireland), Home Quality Mark (UK), Klimaaktiv (Austria) and Miljo Byggnad (Sweden).

The main observations are grouped into common themes that emerged from the research.

##### **3.4.1.1 Design stage assessment of energy performance**

This is a central criteria for all schemes, usually with prerequisite performance requirements. For those schemes operating internationally, the differences between National Calculation Methods is a challenge. For example, the reference building will be described or derived differently. Alternative compliance routes and methods to translate results are required in order to apply the same base requirements. In one case, international applicants had requested reference to an international standard such as ASHRAE.

For office buildings, the use of dynamic simulation models to assess performance does appear to be prevalent for those buildings seeking certification. This was cited as reflecting progress in the sector over the last ten years – particularly as a tool to model passively designed buildings and control of thermal gain.

The units of measurement for operational energy performance are the same as for the Near Zero-Energy Buildings definition (total primary energy in kWh/m<sup>2</sup>.yr and kg CO<sub>2</sub>.eq/m<sup>2</sup>.yr), although performance is generally described in terms of the level of improvement in comparison with a reference building and percentage improvements used to assign points of credits.

In the case of BREEAM and the Home Quality Mark (HQM), a composite indicator is used. This combines:

- a 'fabric first' metric (MJ/m<sup>2</sup>) to focus attention on design of an efficient building envelope;
- a primary energy metric (kWh/m<sup>2</sup>) to focus attention on the system efficiency of the energy used and,
- greenhouse gas emissions (kg CO<sub>2</sub> eq/m<sup>2</sup>) to focus attention on the carbon intensity of the energy used.

This type of indicator is more demanding than building permitting requirements.

#### **3.4.1.2 Accounting for unregulated energy use**

In general this is an imprecise and difficult criteria area, and in many cases a new area of focus. This is because it is not generally addressed in building permitting, so either assumptions or reference values have to be provided or reference has to be made to ratios within dynamic simulation tools.

#### **3.4.1.3 Prevalence of commissioning and quality testing**

The prevalence of commissioning routines and building fabric quality testing appears to vary between countries. In some countries, the use of techniques such as thermal imaging or pressure testing are more common, reflecting national requirements in building permitting, but in others it is not yet required and there is, as a result, less awareness.

Pressure testing is technically challenging to carry out for larger office buildings. Requirements for qualified professionals to carry out routines and testing were also cited in one country as a potential barrier to compliance with criteria.

#### **3.4.1.4 Calculation of embodied primary energy or CO<sub>2</sub> emissions**

In general, this type of performance measurement is considered to be challenging for design teams, requiring time and cost outlay to obtain specialist expertise. Moreover, the more advanced software tools are not free, although this may change in the future. Where a simplified option is available, this is the main route used for compliance – although a more comprehensive alternative compliance option is also available. In one system, the use of different LCA softwares and tools is permitted, provided they have been appraised by the scheme operator.

The EPD databases currently available, even those that are considered the most comprehensive in the EU, cannot always describe all parts of a building. Work is ongoing, or is proposed to be initiated in some countries, to develop generic databases that can be used as a starting point.

Attempts to make this type of calculation more accessible to users have included reducing the number of building materials to be assessed and focussing attention on priority groups of building components/products based on the relatively greater significance of their environmental impacts.

Reference was made in one case to a hierarchical increase in difficulty and accuracy – starting with a basic EPD-based approach, then moving to a 'basic' LCA approach and then moving to a 'whole building' LCA approach.

In one scheme, primary energy and CO<sub>2</sub> calculations are specified separately. It is the intention in the future to bring these together into one calculation.

### **3.4.2 Progress made by scheme harmonisation initiatives**

#### **3.4.2.1 Common Metrics pilot phase 1 and 2, Sustainable Building Alliance**

The Sustainable Building Alliance's initial set of indicators (the 'Common Metrics') included two indicators relevant to MO B1 - non-renewable primary energy consumption (kWh/m<sup>2</sup> functional equivalent) and Global Warming Potential (kg/CO<sub>2</sub> equivalents). Based on the findings from phase one of pilot testing for the Common Metrics, these two indicators were identified as the most mature<sup>69</sup>.

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<sup>69</sup> Sustainable Building Alliance (2011) *Piloting SBA Common Metrics – Phase 1, Technical and operational feasibility of the SBA common metrics*

Phase two of the pilot testing of the Common Metrics is of particular relevance to this study <sup>70</sup>. This is because it has involved the testing of the consistency and comparability of the different LCA methodologies, tools and datasets specified by the major building certification schemes. The participants were Czech Republic (TZUS), Finland (VTT), France (Qualitel/CSTB), Germany (DGNB), Italy (ITC-CNR), Spain (IVE) and UK (BRE).

The pilot was carried out using data for a single residential building in Paris. The following aspects were a focus for analysis and discussion:

- Mandatory and optional contributors (the boundary)
- The choice of service life data for products
- The study period (at building scale)
- The definition and description of indicators
- Compliance with CEN/TC 350 standards

The pilot identified that construction products and equipment can be broadly grouped according to the current availability of EPD data. Table 3.8 illustrates the division into easily available data (List 1) and more difficult to find data (List 2). Some of the key findings from the pilot were as follows:

- A consensus reference building service life was 50 years;
- The use of default service life values for products may not be relevant in all countries/locations because of variations in local conditions;
- At the time, most of the EPD database were not compliant with EN 15804. Some only include reporting on CO<sub>2</sub> not CO<sub>2</sub> equivalent;
- Only in two countries could results be produced for each life cycle phase. This is because EPDs may only be cradle to gate;
- The product list 1 was considered by all countries to be 'feasible without difficulty' provided that products are well described and quantified. The product list 2 is more difficult and even default values may not be available yet;
- In some databases, impacts from the replacement of products are included in the production stage;
- There was a lack of consistency as to how to account for the lack of an EPD for a product – a hierarchy of preferences could be developed;
- The end-of-life phase is not considered consistently in each country;

The findings informed a series of recommendations that are directly relevant to the setting of common rules for the calculation of embodied non-renewable primary energy and/or Global Warming Potential at EU level. A list of mandatory contributors was proposed as: roof, load bearing structure, exterior and basement walls including windows, internal walls, floor slabs, foundation, floor finishes/coverings, decorative wall finishes/coatings and doors.

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<sup>70</sup> Sustainable Building Alliance, *Beyond research to operational application and comparability*, Phase 2 summary presentation, September 2014

Table 3.8 The product and equipment 'families' available grouped according to ease of availability of LCA data

Families of products	List 1	List 2
Roof	9	1
Load bearing structure	8	-
Exterior and basement walls including windows	13	2
Internal walls	4	-
Floor slabs	4	-
Foundation	5	-
Floor finishes / coverings	19	1
Decorative wall finishes / coatings	6	-
Doors	3	-
Heating / cooling systems	-	14
Lighting equipment	-	6
Heat or power generating equipment	-	1
Electrical distribution system	-	9
Water and sewerage system	-	11
Urinals, WCs, taps, baths, showers	-	4
TOTAL	71	49

Source: Sustainable Building Alliance (2014)

### 3.4.2.2 Common European Sustainable Building Assessment, CESBA

The CESBA assessment scheme includes six criteria that address energy demand and supply in its v1.1 indicator catalogue.

The criterion are based on the Passive House Planning Package (PHPP). They comprise the following metrics that shall be calculated:

- Heating demand in kWh/m<sup>2</sup>.yr
- Cooling demand in kWh/m<sup>2</sup>.yr
- Primary energy demand in kWh/m<sup>2</sup>.yr
- Emissions of CO<sub>2</sub> equivalents/m<sup>2</sup>.yr
- Solar PV power plant equivalents (annual yield 3.5 kWh/m<sup>2</sup>.yr)
- Comparison of actual energy consumption in relation to initially predicted values

Taken together heating and cooling demand are weighted the highest (200 points in total), followed by primary energy (125 points), CO<sub>2</sub> equivalents (75 points), solar PV power plant equivalents (50 points) and actual energy consumption comparison (10 points).

### 3.5 Identification and screening of potential performance indicators

#### 3.5.1 Long list of macro-objective 1 direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope			Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage	Building aspects			
<b>1a. Operational energy use and GHG emissions</b>							
<b>Operational carbon emissions</b>	kgCO <sub>2</sub> e/m <sup>2</sup> .yr	B6 Operational energy	Concept design Technical design Construction In-use	Energy used for heating, cooling, domestic hot water and auxiliary services. Electricity use for lighting not always included (e.g. residential buildings in Flanders region, BE)	EPBD, EN 15603 WRI's GHG protocol <sup>71</sup>	-	FS CC AR
<b>(operational) Primary energy consumption</b>	kWh/ year; normalised per m <sup>2</sup> floor area or per occupant	B6 Operational energy	Concept design Technical design Construction In-use	Energy used for heating, cooling, domestic hot water and auxiliary services. Electricity use for lighting not always included (e.g. residential buildings in Flanders region, BE)	EN 15603 Steady-state or dynamic simulations	According to national and regional regulation or certification scheme	FS CC
	E-value				EPBD in selected MS Steady-state simulations		FS
	Energy label				EPBD in selected MS (e.g. The Netherlands) Steady-state simulations		FS

<sup>71</sup> Greenhouse Gas Protocol (2012) *Greenhouse gas protocol*, [online] available at: <http://www.ghgprotocol.org/> [Accessed 20/5/2016]

<b>Reduction of energy consumption</b>	% compared to reference value	B6 Operational energy	Concept design Technical design Construction In-use	See "primary energy consumption"	EN 15603	According to national and regional regulation or certification scheme	FS AR
<b>Measured energy consumption</b>	kWh/m <sup>2</sup> .year	B6 Operational energy	In-use	energy use related to property (HVAC, lighting, outdoor lighting, lifts) and electricity use related to users	Total energy consumption according to the energy bills	-	FS AR
<b>1c. Embodied energy use and GHG emissions</b>							
<b>Total primary energy consumption</b>	kWh/year; normalised per m <sup>2</sup> floor area or per occupant	A1-3 Production A4-5 Construction B1-B7 Use <u>Optional:</u> C1-C4 End of Life	Technical design and/or construction <u>Recommended:</u> Concept design	See "embodied carbon" and "operational carbon"	EN 15978 EN 15804	-	FS CC AR

<b>Embodied carbon</b>	tCO <sub>2</sub> e or normalized kgCO <sub>2</sub> e/m <sup>2</sup> ]	A1-3 Production A4-5 Construction <u>Optional:</u> B1-B5 Use - Use - Maintenance - Repair - Replacement C1-C4: End of Life	Technical design and/or construction <u>Recommended:</u> Concept design	Superstructure, substructure, fit-out, façade, project-specific building components (e.g. PV-panels)	EN 15978 <u>Tools:</u> ECO <sub>2</sub> (Skanska Sweden), Klimagassregnskap (Norway), LCA-tools <u>Databases:</u> Inventory of Carbon & Energy (ICE) database <sup>72</sup> ; Ecoinvent	Large variety in assumptions for lifespan, life cycle stages and scope	FS
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Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

<sup>72</sup> Circular Ecology Ltd (2015) *Embodied energy and carbon - The ICE database*, [online] available at: <http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html> [Accessed 20/5/2016]



### 3.5.2 Long list of macro-objective 1 supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>B1a. Operational carbon</b>							
<b>Proportion of renewable primary energy production</b>	% (kWh.year)	B6 Operational energy	Technical design In-use	Renewable energy generation technologies	EN 15603	-	FS
<b>Net energy demand for heating</b>	kWh/m <sup>2</sup> .yr	B6 Operational energy	Concept design Technical design Construction In-use	Net energy demand for heating	EN 15603	-	FS
<b>Net energy demand for cooling</b>	kWh/m <sup>2</sup> .yr	B6 Operational energy	Concept design Technical design Construction In-use	Net energy demand for cooling	EN 15603	-	FS
<b>'Unregulated' electricity use</b>	kWh/year; normalized per occupant	B6 Operational energy	In-use	Plug loads		-	
<b>Thermal insulation level of the building envelope</b>	U <sub>average</sub> [W/m <sup>2</sup> .K]	B1-7 Use	Concept design Technical design	Weighted average U-value of building envelope and its components	EN 15603	-	FS

	K-value	B1-7 Use	Construction	Similar to $U_{average}$ , but taking into account form-factor of building (compactness)	Regional EPBD requirements (Flanders, Belgium)	-	
<b>Baseload demand</b>	kW/year	B6 Operational energy	In-use	Electricity consumption during vacant hours; energy used for heating is not included	Monitoring (metering) data	Measurement of hourly electricity consumption required	FS
<b>Airtightness</b>	V50 [m <sup>3</sup> /h]	B1-7 Use	Construction	Air leakage of the building envelope	Pressurization test according to EN 13829	test performed at 50Pa	CC
	v50 [m <sup>3</sup> /m <sup>2</sup> .h]	B1-7 Use B1-7 Use	Handover and close-out Construction			test performed at 50Pa; normalized by surface area of building envelope	CC
	n50 [m <sup>3</sup> /m <sup>3</sup> .h]		Handover and close-out			test performed at 50Pa; normalized by volume	FS

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 4. Macro-objective 2: Resource efficient material life cycles

### 4.1 Defining the macro-objective's scope and focus

#### 4.1.1 Policy and technical background to selection of the macro-objective

In the first working paper of this study, the *Construction Products Regulation*<sup>73</sup> was identified as an important reference point for resource efficiency. Annex 1 of the Regulation lays down 'basic requirements for construction works' which include specific reference to emissions to the environment (requirement 3) and the sustainable use of natural resources (requirement 7). Basic requirement 7 is particularly relevant because it states that:

*'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) reuse 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.'*

Of relevance to these requirements is the *Waste Framework Directive*<sup>74</sup> which lays down requirements for the priority waste stream Construction and demolition waste (CDW). The Directive requires that:

*'Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the List of Wastes shall be prepared for re-use, recycled or undergo other material recovery" (including backfilling operations using waste to substitute other materials).'*

The *EU action plan for the Circular Economy* has now also become a significant policy reference. Construction and demolition waste was identified as a priority area. The significant volume of waste, the wide variance in re-use and recycling rates across the EU and the role of the construction sector in influencing the performance of buildings throughout their life are highlighted. The need to establish common standards and protocols for waste sorting is identified, with specific reference also made to the treatment of hazardous waste. Design improvements to buildings to increase their durability and recyclability are also emphasised.

#### 4.1.2 The intended scope and focus

The macro-objective is to optimise building design, engineering and form in order to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts.

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<sup>73</sup> 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

<sup>74</sup> Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste

In practical terms, the macro-objective will focus on a number of aspects of material resource efficiency. This will comprise:

- structural design for material efficiency;
- recycled/reused input material;
- construction and demolition waste minimisation;
- future design for adaptability;
- future design for deconstruction;

The overall objective shall be to reduce waste, optimise material use intensity and reduce the life cycle environmental impacts of designs and material choices. The overall approach will be construction material neutral.

## **4.2 Cross-cutting investigation of the macro-objective's implementation**

### **4.2.1 Private and public sector building practices**

#### **4.2.1.1 The potential for structural design and material optimisation**

A building's structure, comprising its superstructure, substructure (foundations and basements) and envelope, account for the most significant proportion of its material mass, the production of which is in turn associated with a range of environmental impacts, including embodied CO<sub>2</sub> emissions.

An international study and practitioner survey undertaken by Arup looked at the scope for building assessment criteria to incentivise lower impact structural design<sup>75</sup>. It concluded that current assessment schemes could do more to encourage design optimisation and that a focus on material efficiency would currently be more effective than promoting LCA criteria. It recommended that:

*'measured material efficiency should be rewarded. This could form an lower tier entry to an LCA based credit'*

It also found that although there are some recognised trade-offs between material efficiency and embodied CO<sub>2</sub> – for example, the use of post-tensioned concrete in place of in-situ concrete – in general, the outcomes would deliver buildings with improved environmental performance.

Analysis has shown that for all forms of structure there is significant scope to optimise the material use in any given frame type<sup>76</sup>. Figure 4.1 Illustrates the potential for range of embodied CO<sub>2</sub> for any given structural frame.

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<sup>75</sup> The Institution of Structural Engineers, *The value of structural engineering to sustainable construction*, Final report prepared by Arup, 6th March 2012.

<sup>76</sup> Kaethner, S.C and Burridge, J.A. Embodied CO<sub>2</sub> of structural frames, *The Structural Engineer*, May 2012.

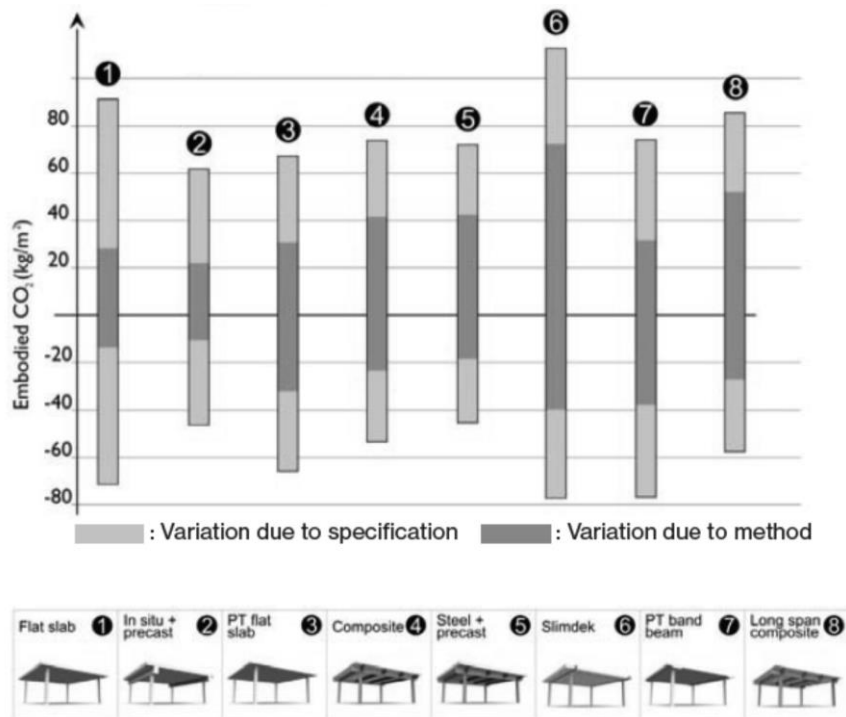


Figure 4.1 Potential variation in embodied CO<sub>2</sub> of commercial building structural frame due to method and specification

Source: Kaethner and Burrige (2012)

Following on from the recommendation of the Arup study, the first Working Paper identified two broad areas of potential to reduce the mass of materials used in building structures:

1. Consideration of different building forms and massing: Homes that share party walls and floors have a reduced surface area to volume ratio, and therefore have the potential to save on both material mass and energy for heating and cooling. Taller structures also in general require greater load bearing capacity, and so require more material mass.
2. Optimisation of structural designs: Within the limits of Eurocode safety factors and locational constraints (e.g. wind loads, seismic activity) there can still exist the potential to optimise the design and choice of structural system in order to reduce the material mass required for a given load bearing capacity and/or floor plate.

The potential for indicators of the material efficiency of structures, as well as the relationship between mass and embodied CO<sub>2</sub>, has been explored both as part of the field studies (see Section 4.3), which compare and contrast the experience and improvement potential of different strategies used for steel and concrete structures, as well as a review of state-of-the-art analysis and surveys of structural design efficiency.

#### 4.2.1.1.1 The relationship between residential building form and material mass

The LCA review carried out in Working Paper 1 identified residential building form as a significant potential influence on resource efficiency, both in terms of energy and material use. By minimising dwelling surface area to volume ratios, the potential CO<sub>2</sub> emissions and therefore global warming potential (GWP) can in turn also be reduced. Moreover, compact building forms require progressively less materials as party walls and floors are shared.

Nemry et al (2008)<sup>77</sup> and Cuéllar-Franca and Azapagic (2012)<sup>78</sup> identified that multi-family (semi-detached and terraced) and high rise buildings tend to be more energy and material efficient than single family dwellings. Moreover, this finding is also supported by Norman et al (2006)<sup>79</sup>, who analysed building construction, use and associated transport using an economic input-output life cycle assessment model, and Steemers (2003), who identified the potential to optimise the energy efficiency of the built form by increasing residential densities up to 200 dwellings per hectare (0.01 km<sup>2</sup>)<sup>80</sup>.

Drawing upon one of the literature sources, an indicative comparison of three residential building forms is presented in table 4.1. The comparison includes 80% of the materials that contribute to the material mass and illustrates the positive relationship between compact form, fabric heat loss and material mass. In figure 4.1, this relationship is cross-checked for trade-offs in the embodied GWP of the construction materials. Here, again, the relationship can be seen between form and GWP.

Table 4.1. Comparison of the material intensity of three residential forms

Key Variables	Detached home	Semi-detached home	Terraced home
<b>LCA assumptions</b>			
Household size (persons)	2.3	2.3	2.3
Bedrooms	4	3	2
Useable floor area (m <sup>2</sup> )	130	90	60
Fabric heat loss (W/K)	220	170	120
<b>Building materials (kg)</b>			
Brick			
- Inner leaf	22,302	19,199	9,809
- Outer leaf	43,828	31,747	20,193
- Other	16,144	13,362	10,956
Cement mortar	11,662	8,447	5,373
Concrete			
- Block (aerated)	14,577	10,559	6,716
- Slab	19,615	16,157	13,094
- Other	15,600	10,824	7,200
<b>Material total (kg)</b>	<b>143,728</b>	<b>110,295</b>	<b>73,341</b>

Source: Cuéllar-Franca and Azapagic (2012)

<sup>77</sup> Nemry et al (2008) *Environmental improvement potentials of residential buildings (IMPRO-Buildings)*, Joint Research Centre IPTS, European Commission.

<sup>78</sup> Cuéllar-Franca.R.M and A.Azapagic, *Environmental impacts of the UK residential sector: Life cycle assessment of houses*, Building and Environment 54 (2012) p.86-99

<sup>79</sup> Norman.J, MacLean.H, and C.Kennedy, Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions, *Journal of Urban Planning and Development*, March 2006, Vol. 132, No. 1 : pp. 10-21

<sup>80</sup> Steemers.K, Energy and the city, density, buildings and transport, *Energy and Buildings* 35 (2003) 3–14

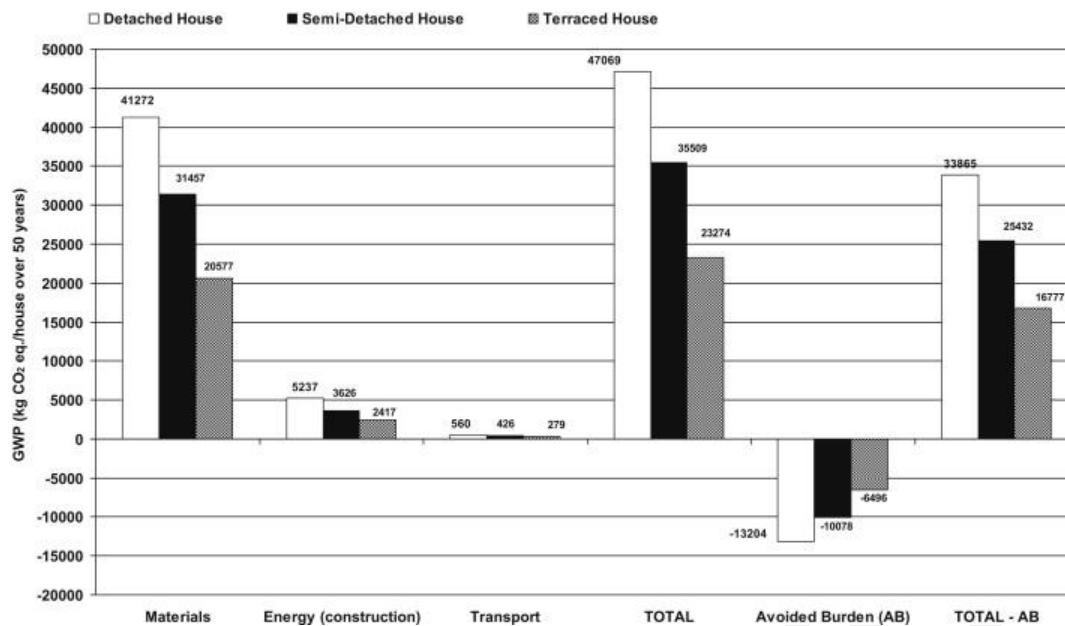


Figure 4.2 Comparison of GWP (construction stage) for three residential forms

Source: Cuéllar-Franca and Azapagic (2012)

The potential improvement in GWP from building more compact residential forms can only be identified by normalising the performance to dwelling or occupant instead of  $m^2$ . However, trade-offs also exist between density, and heating and cooling needs. Strømen-Andersen and Sattrup (2011)<sup>81</sup> and Trigaux et al (2014)<sup>82</sup> found that, in northern climates, passive solar gain and daylight can be adversely affected.

#### 4.2.1.1.1 The relationship between building size, height and material mass

In order to understand further the potential influence of building size and height, the findings from a recent reference study by De Wolf et al (2015)<sup>83</sup> have been examined in more detail. Notably, the author has worked in conjunction with a number of leading engineering companies, including Arup and Thornton Tomasetti, in order to access data and practical insight, and was therefore also the subject of an interview by the study team.

The study combined a review of previous studies, as well as analysis using confidential data of the material mass and embodied  $CO_2$  emissions for over 200 completed building structures, including 29 offices and 41 residential buildings. The published findings highlight that with an increasing number of storeys, the mass of a structure increases due to design features required for gravity loads and the need for resistance of lateral wind loads, as illustrated in Figure 4.2. This assertion is further supported by a study by Foraboschi et al (2014)<sup>84</sup>.

<sup>81</sup> Strømen-Andersen.J and P.A.Sattrup, *The urban canyon and building energy use: urban density versus daylight and passive solar gains*, Energy and buildings, 43(2011) p.2011-2020

<sup>82</sup> Trigaux.D, Allacker.K and F.de Troyer, *A simplified Approach to integrate Energy Calculations in the Life Cycle Assessment of Neighbourhoods*, Submission to the 30th International PLEA Conference, 16-18 December 2014, CEPT University, Ahmedabad

<sup>83</sup> De Wolf.C, Yang.F, Cox.D, Charlson.A, Hattan.A.S and J.Ochsendorf, *Material quantities and embodied carbon dioxide in structures*, ICE Proceedings, August 2015

<sup>84</sup> Foraboschi.P, Mercanzin.M and TrabuccoUniversità.D, *Sustainable structural design of tall buildings based on embodied energy*, Energy and buildings, Elsevier, 68 (2014) 254–269

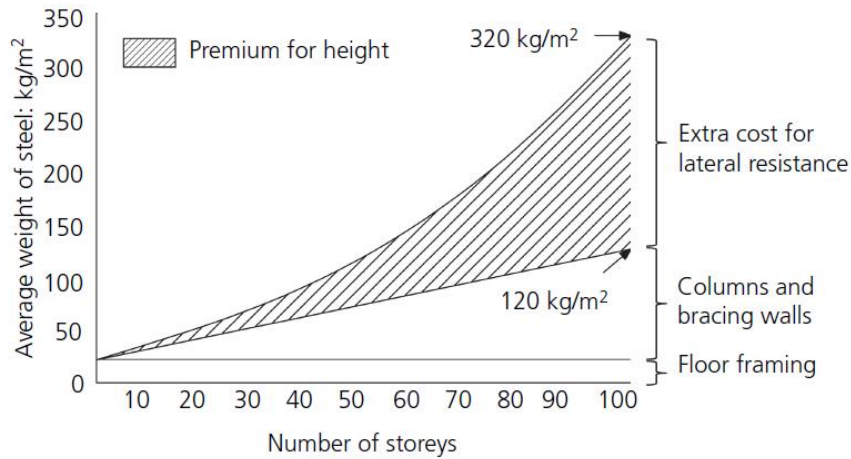


Figure 4.3 Indicative weight of steel per number of stories

Source: De Wolf (2015)

The analysis carried out confirmed an increase in the amount of material per square metre in function of height and size of building. The relationship to embodied CO<sub>2</sub> for the building database is shown in Figure 4.4. Analysis by Foraboschi et al (2014) found that the embodied energy premium for building height can be less than that for material mass, but that in some cases lower mass solutions such as composite floors may have a higher embodied primary energy or CO<sub>2</sub> eq/m<sup>2</sup>.

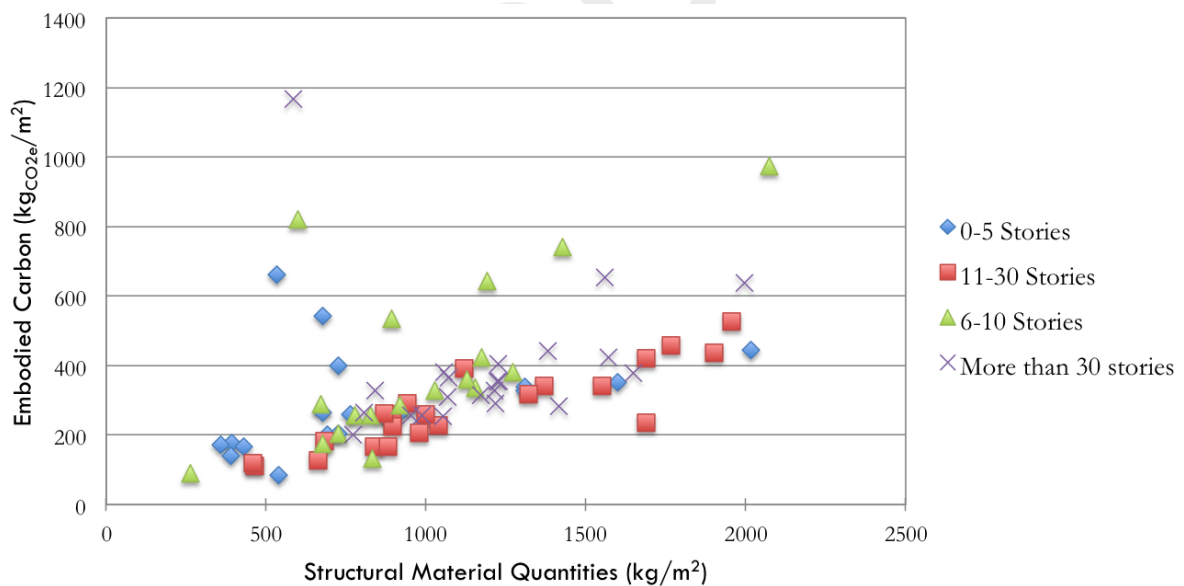


Figure 4.4 Relationships between building height, embodied CO<sub>2</sub> equivalents and Structural Material Quantities

Source: courtesy of De Wolf (2016)

A main finding was that it is better to improve material efficiency on a case by case basis rather than selecting one specific structural system over another. This is in part because for all building sizes and forms improvements can be made. This finding is supported by analysis by Arup (Kaethner and Burrige 2012). De Wolf (2015) furthermore suggests that material and embodied CO<sub>2</sub> equivalent metrics could be used as tools to encourage improved building design when



benchmarked in comparison to other buildings of similar floor area, size and/or height.

#### 4.2.1.1.3 Evidence for the potential for structural design optimisation to reduce material mass

Application of the Eurocode methodologies to the design of structures in combination with the clients brief will dictate the structural design tolerances of a multi-storey building. However, it has also been postulated in discussion with stakeholders that 1) structures and the grades of materials used may, in some cases, be over specified and that 2) with careful design and new construction systems there may be scope for materials savings to achieve the same design and functional requirements.

Evidence for the potential for design reductions in material mass has therefore been investigated, with a focus on concrete and steel. The building database compiled by De Wolf (2015) has also been analysed to check the relationship between structural material quantities and embodied CO<sub>2</sub>, as it is considered important to identify the likelihood of any significant trade-offs<sup>85</sup>. The main sources for the data include the Bills of Quantities from major projects by the engineers Arup and Thornton Tomasetti. The results are shown in Figures 4.5 for residential buildings and 4.6 for office buildings.

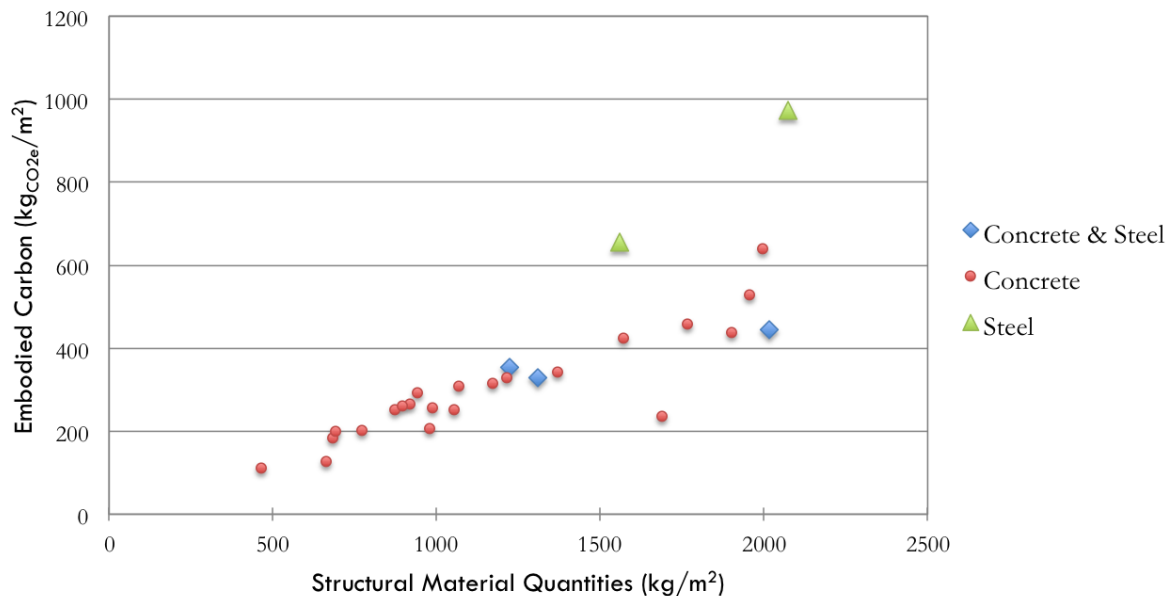


Figure 4.5 Relationship between residential building embodied CO<sub>2</sub> and Structural Material Quantities

Source: courtesy of De Wolf (2016)

<sup>85</sup> De Wolf, C., 2016. Personal communication using project data compiled from the Database of Embodied Quantity Outputs (deQo)

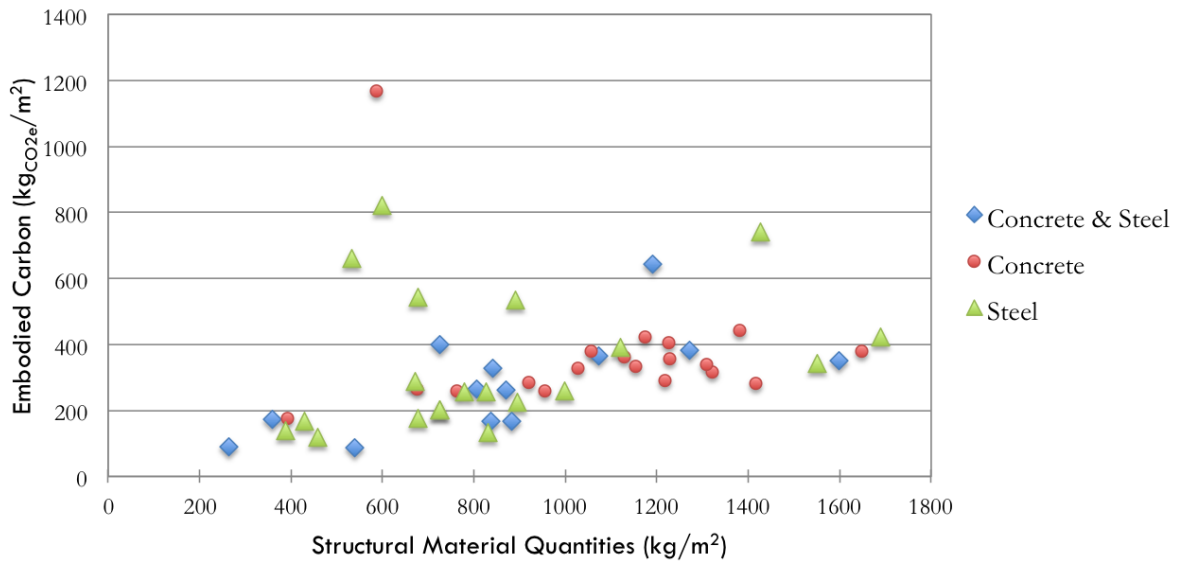


Figure 4.6 Relationship between office building embodied CO<sub>2</sub> and Structural Material Quantities

Source: courtesy of De Wolf (2016)

#### Concrete Usage Index, Singapore

For concrete, the Concrete Usage Index (CUI), which has been developed and applied in Singapore, provides evidence for the potential to reduce concrete mass<sup>86</sup>. CUI is defined as the ratio of the volume of concrete in m<sup>3</sup> to the internal floor area in m<sup>2</sup>. The CUI scoring is summarised in Table 4.2. It has been applied as a criterion in Singapore's Green Mark building certification scheme.

The CUI performance for Green Mark certified large residential and non-residential buildings tends to range between 0.38 and 0.50. Example projects cited by the Singapore Building and Construction Authority (BCA) that have achieved a CUI in this range had implemented techniques to achieve reductions in concrete usage in the range of 20-30%, such as void formers, hollow core slabs and precast pre-stressed planks.

Poor performing buildings showed CUIs as high as 0.6 (residential) and 0.8 (non-residential). Additional further improvements focussed on the concrete mix design, with substitution of the cement fraction having the benefit of reducing embodied CO<sub>2</sub> emissions.

Table 4.2 Scoring of Concrete Usage Index (CUI) within Green Mark

Project CUI (m <sup>3</sup> /m <sup>2</sup> )	Points allocation
≤ 0.7	1 point
≤ 0.6	2 points
≤ 0.5	3 points
≤ 0.4	4 points
≤ 0.35	5 points

Source: BCA (2012)

<sup>86</sup> Building and Construction Authority (2012) *A guide on Concrete Usage Index*, BCA Sustainable Construction Series - 6, Singapore

### *Steel structural utilisation, University of Cambridge*

For steel, an analysis by the University of Cambridge in the UK 23 steel framed building designs was reviewed<sup>87</sup>. The data was supplied by three leading UK design consultancies. The aim was to identify how much steel could be saved through more efficient design. The utilisation efficiency of each beam within a given structure was analysed in order to determine the potential to reduce steel mass without compromising design performance requirements and safety factors.

The study found that, on average, the utilisation rate of the beams analysed was less than 50% of their capacity. That is to say that their full load bearing capacity is not being utilised. A significant potential reason was identified as 'rationalisation' – the selection of beams based on availability, time and cost. Moreover, they suggest that aspects of structures are '*not explicitly designed*'.

Reference to a catalogue of standard beams during the analysis suggested that, on average, 36% of the beams' mass could be saved. To achieve this scale of saving they recommend the greater use of existing design and optimisation software. They also recommend that building assessment schemes incentivise improved utilisation rates, and that an initial step could be to '*mandate reporting of average U/R* [Utilisation Rates).

#### **4.2.1.2 Designing for deconstruction and disassembly**

As Working Paper 1 highlighted, the material inventory held within buildings represents a substantial proportion of the mass flow and embodied environmental impacts of materials in the EU economy.

Building elements such as structures, envelopes and facades account for the majority of the embodied environmental impacts of constructing a building, so any progress to achieve 'circularity' by reusing these materials – either in situ within a new building or on another site – or by recycling them to make new building products, will serve to progressively reduce the embodied life cycle impacts of the building sector as a whole. The potential to reuse insitu elements of existing buildings in new buildings will be explored further in this section.

##### **4.2.1.2.1 Identifying the factors to consider**

A major barrier to design for deconstruction is the disconnect between decisions made at the design stage of a building and those that may be made several decades later when the building reaches the end of its life. In this respect, assessment schemes and reporting tools may therefore have an important short to medium term role in incentivising such practices and providing reference to tools and guidance.

Research by Arup for the Institution of Structural Engineers (IStructE) highlighted that although schemes such as BREEAM and DGNB include criteria that reward design for deconstruction practices, not all criteria provide a clear framework for assessing such practices, which in turn may not provide clear instructions to design teams and contractors<sup>88</sup>. Quantifiable methodologies that have been developed by DGNB and the BRE are briefly examined in Section 4.2.1.2.3 and 4.2.1.2.4.

A study carried out by Charlson (2013) for Arup and the Chartered Institute of Building (CIOB) in the UK focussed specifically on how to improve design for deconstruction practices. It provides useful insight from an international

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<sup>87</sup> Moynihan.M.C and Allwood,J.M, *Utilisation of structural steel in buildings*, Proceedings of the Royal Society, 470 (2014)

<sup>88</sup> The Institution of Structural Engineers, *The value of structural engineering to sustainable construction*, Final report, Prepared by Arup, 6th March 2012.

literature review and survey of 26 demolition industry professionals <sup>89</sup>. The literature review identified four current barriers to material reuse:

- Building designs: Current construction methods and materials do not support the recovery of materials. Examples includes contamination with hazardous materials, entanglement of services in structural elements and the use of composite steel and concrete systems.
- Demolition processes: Current schedules and practices do not support the recovery of materials in a useable state. Examples include the use of shears to cut steel sections because of welded joints or the limit of time.
- Logistics systems: There is a lack of space to store reclaimed materials. An example is the storage of reclaimed steel sections before they may be required in new construction. Even if sections are recovered, the types of modifications required may be prohibitive.
- Markets: There is a lack of demand for reclaimed materials. This may be constrained by the limited supply and variability in sizes of elements or sections versus those which may be required. Changes in standard specifications over time have resulted in a greater variety of building elements. Uncertainty about material properties and use history may also play a role.

The potential to address these barriers as part of an approach to 'design for deconstruction' is highlighted.

The Finnish ReUSE project also sought to address the potential and challenges currently facing the reuse of elements from existing buildings and design for re-use in new buildings <sup>90</sup>. The project had a specific focus on larger structural elements in commercial, industrial and residential buildings (columns, beams, wall panels, and floor and roof elements) including those made from timber, steel and concrete. The project's findings broadly accord with those of Charlson (2013), further serving to highlight the complexity of seeking to re-use building components and elements. Figure 4.7 serves to illustrate the complex interactions between the different actors involved in the re-use process.

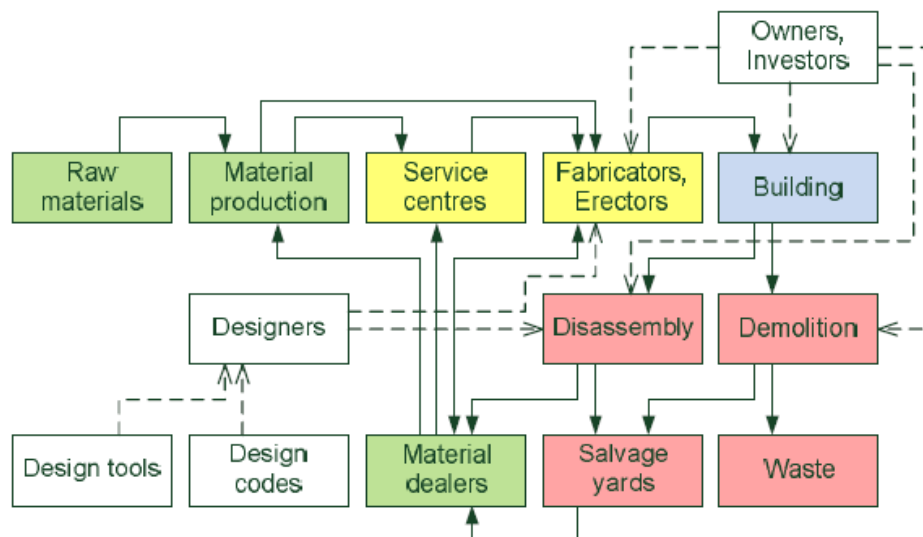


Figure 4.7 Major roles in the re-use process and their interaction

Source: VTT (2014)

<sup>89</sup> Charlson, A., *Designing for the deconstruction process*, Final report produced for the Sir Ian Dixon Scholarship, 25th February 2013, UK

<sup>90</sup> VTT Technical Research Centre of Finland and Tampere University of Technology (2014) *Re-use of structural elements of building components*.

A survey of construction and demolition professionals in Finland highlighted that beams and columns made of steel or concrete offered the best near term reuse potential. Timber beams, columns and cross laminates could have improved potential in the future. The following additional observations were made:

- Timber: Beams, columns and CLT were highlighted as having potential.
- Concrete: Beams and columns were seen to have good prerequisites for reuse, but the lack of an established market was seen as a major obstacle. For panels and slabs, the difficulty of deconstruction was seen as the first obstacle followed by market-related issues.
- Steel: Construction technology was not seen to hinder the reuse of steel components, but rather the lack of established practices.

The study also identified the practical potential to re-use concrete panels from the 1960's and 1970s panel built (prefabricated) lower rise detached housing, reflecting similar practices in the former East Germany <sup>91</sup>.

To develop further an approach to design for deconstruction, Charlson (2013) compiled the most commonly cited actions in currently available guidance. Table 4.3 lists the ten actions with the greatest number of citations.

*Table 4.3 Design for deconstruction actions cited in current guidance*

<b>Actions cited as contributing to design for deconstruction</b>	<b>Number of sources that cited action</b>
Use reversible mechanical/non-chemical connections	15
Ensure elements of the building are independent and separable (structure, envelope, services, fit out)	12
Use standardised elements	10
Use non-composite floor systems	10
Permanently mark materials with properties	10
Ensure as-built drawings are available	9
Develop a deconstruction plan during design phase	8
Avoid use of resins, adhesives and coatings	8
Ensure post-construction ease of access to fixings	8
Do not use in-situ concrete	7
Avoid use of hazardous materials	7
Use modular elements	6
Use prefabricated elements	6
Use lime-based mortar with masonry	6
Minimal number of materials and components	6
Think about early in design process (scheme & design development)	6
Use components of singular materials	5
Train all team members on DfD	5
Establish feasibility of element reuse	5
Design in tie offs for deconstruction	4
Provide construction plan	4
Use durable materials	4
Size components for manual handling	4
Include information on deconstruction techniques	3
Do not use structural grout with precast elements	3

<sup>91</sup> IEMB (2007) *Recycling Prefabricated Concrete Components – a Contribution to Sustainable Construction*, Neue Ergebnisse, Germany

Source: Charlson (2013)

These potential actions were verified with demolition industry professionals in a survey. This resulted in two main actions being identified that would need to be encouraged:

1. Building information: Information about the building should be passed on, to include full as-built drawings and a deconstruction plan.
2. Design stage actions: A number of specific design actions should be taken to enable the separation of materials and elements.

In relation to the second point, the design actions identified as being of greatest potential significant were:

- Independent and easily separable elements of the building *e.g. structure, envelope, services & internal finishes*;
- Ease of access to connections;
- Mechanical and reversible (not chemical) connections;
- Avoidance of resins, adhesives or coatings on the elements to be disassembled;
- Avoidance of in-situ concrete structures;
- Avoidance of composite floor constructions;
- Prefabricated elements should be permanently marked with details of their properties.

VTT and TUT (2013) came to broadly similar findings, with the addition of a focus on long life and easy maintenance of structural elements and the easy removal and recyclability of external and internal cladding materials and coatings applications that have to be renewed. Avoidance of the use of hazardous materials that may hinder recycling was also highlighted.

It is important to note that at least two of the actions identified by Charlson (2013) would mitigate against the use of currently widely used construction techniques (in-situ, poured concrete) and/or techniques that are used to speed up the construction process and which can facilitate the future flexibility of structures (composite floors). For this reason, it was recommended that in cases such as the use of in-situ concrete then a focus should be put on design for adaptability, so as to mitigate an early end of life for the structure.

#### **4.2.1.2.2 Identification of tools that quantify the potential of design for deconstruction and disassembly**

The Institution of Civil Engineers (ICE) introduced the concept of a quantifiable Deconstruction Recovery Index (DRI) as part of their 2008 Demolition Protocol <sup>92</sup>. The DRI is described as the percentage, in terms of area (m<sup>2</sup>), of the structure, cladding, flooring/ceiling elements, that is capable of being dismantled without significant risk of damage. This DRI can then be used to establish a deconstruction target.

Both DGNB and the BRE Trust have developed tools for quantifying design for deconstruction. The DGNB tool supports a new-build office scheme criteria and comprises category scoring for indicators of the ease of disassembly, scope of disassembly and viability of disassembly. The BRE Trust have recently developed an outline Design for Deconstruction methodology for new-build residential buildings <sup>93</sup>.

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<sup>92</sup> Institution of Civil Engineers (2008) *Demolition protocol*, UK

<sup>93</sup> BRE Buzz, *Design for Deconstruction – helping construction unlock the benefits of the circular economy*, Accessed May 2016, <http://brebuzz.net/2015/12/04/design-for-deconstruction-helping-construction-unlock-the-benefits-of-the-circular-economy/>

In the study previously described by Charlson (2013), a proposal was put forward for a 'Structure Recoverability Index' (SRI), but it is not understood to have been applied more widely. There is also currently ongoing work in a number of Horizon 2020 projects to develop design tools (e.g. BAMB: Buildings as Material Banks<sup>94</sup>) and this may also serve in the future to inform indicator development.

In the Netherlands, a focus by the Government on promoting the concept of 'circular buildings' has prompted a range of central and local government projects, some of which are examined as part of the field studies in Section 4.3. This practical experience is likely to provide feedback on design criteria and will be taken into consideration as part of this study.

Whilst a new ISO standard 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17, initiated by proposals from Canada, it is not clear at this stage whether this will result in a quantifiable design assessment tool.

#### 4.2.1.2.3 BRE Design for Deconstruction methodology

The BRE methodology focusses on the types of materials and components used, the way they are put together and their potential to be taken apart. The methodology has been applied to a number of case studies of residential buildings. A schematic of the methodology is provided in Figure 4.8.

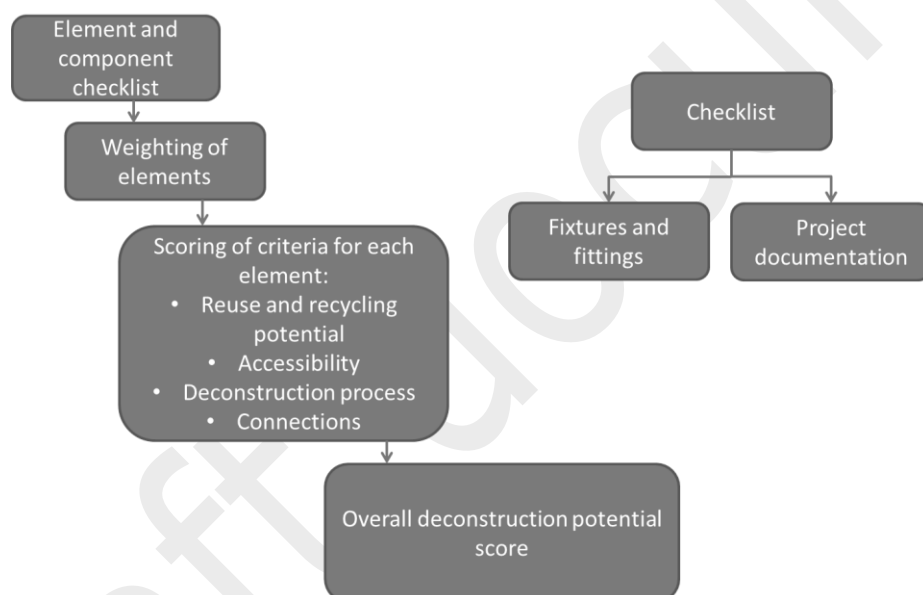


Figure 4.8 Schematic of BRE Design for Deconstruction methodology

Source: BRE (2015)

The methodology groups building elements into: foundations and ground floor, other floors, roof, external walls, other walls and finishes, floor finishes, building services and sanitary ware. Fixtures and fittings are also considered, if information is available. The relative importance of each building element is weighted according to their embodied CO<sub>2</sub>e prior to scoring them according to their deconstruction potential. The weighting applied is adjusted according to the form of house and building materials.

<sup>94</sup> BAMP project, *Building as Material Banks: Integrating Materials Passports with Reversible Building Design to Optimise Circular Industrial Value Chains*, Horizon 2020 project, [http://cordis.europa.eu/project/rcn/196829\\_en.html](http://cordis.europa.eu/project/rcn/196829_en.html)

#### 4.2.1.2.4 DGNB deconstruction and disassembly methodology

Based on current standards and practice, the only mature indicators to quantify design for deconstruction or disassembly potential appear to be those that form part of the German DGNB scheme. Two distinct criteria are currently used – one in the German version of the scheme and another in the International (CORE 14) version. The criteria are compared and contrasted in this section.

The German version of DGNB for office and residential buildings (2015) currently includes a category scoring indicators of the recyclability of material selection and ease of disassembly. These categories replaced the original 'deconstruction and disassembly' categories that are still contained within the CORE 14 International criteria (see below). This change was made in order to broaden the scope of the original category scores, which were too narrow in their focus. A brief overview of how the criteria scoring works is provided in table 4.4.

Table 4.4 Scoring for DGNB Germany TEC 1.6 Disassembly and Recyclability criterion

Indicators	Category scoring	Category description
Recyclability with material identification (at material level)	Level A	a recycling or reuse of the building product is possible or recycling into a product with a similar field of application or function.
	Level B	Reuse or recycling as another product with high value (high performance) (e.g. wood beam into wood panel)
	Level 'Standard'	An identification all of materials that do not achieve level A or B recyclability shall be made. This can include all materials and components that are only suitable for energy recovery
Easy to disassemble (at component level)	Level 'construction that is easy to disassemble'	It is possible to remove the component or make a homogenous separation of the building layers without any damage. A further separation of homogenous materials is not required if the material layers are from the same material group (e.g. clay plaster from clay brick, or wood paneling from timber construction).
	Level 'removal without any damage'	It means, that for this component a reuse for the same purpose, or further use for a different purpose is possible. It also means that it is possible to remove these elements without damaging their connection to the entire building and to components to which they are connected.
	Level 'homogeneous separation of building layers'	It means that material recovery for recycling is possible without limitations.
	Level 'Standard'	A building construction that does not meet any of the above listed criteria. .

Source: DGNB (2014)

To reduce the complexity of verification, compliance is necessary only for 'standard building components'<sup>95</sup>. In order to assess the criterion a number of

<sup>95</sup> Standard building element are those have the same design and/or the same construction and account for more than 20% of the respective building component according to the DIN 276.



specific component groups are therefore defined. These are further broken down into material and elemental levels, corresponding to the two categories. The component groups and the two levels are presented in table 4.5. For each of the components listed in table 4.5, further specific sub-components are listed that shall be assessed.

*Table 4.5 Definition of 'relevant component groups'*

<b>Recyclability with material selection (material identification level)</b>	<b>Easy to disassembly (building construction level)</b>
External walls	External walls
Internal walls	Internal walls
Ceiling	Ceiling
Roof	Roof
Structure	
Foundation	

*Source:* DGNB (2014)

The International version of DGNB for office buildings (2014) currently includes a category scoring indicators of the ease of disassembly, scope of disassembly and viability of disassembly. Four component categories are considered:

1. Building services
2. Non-structural building components
3. Non-load bearing components of the building shell
4. Load-bearing components of the building shell

A brief overview of how the criteria scoring works is provided in table 4.6. The two indicators are weighted equally and are intended to be complemented by a plan describing the 'means and financial responsibilities for controlled disassembly'.

*Table 4.6 Scoring for DGNB International TEC 1.6 Deconstruction and disassembly criterion*

<b>Indicators</b>	<b>Category scoring</b>	<b>Category description</b>
Ease of disassembly	Very high	Disassembly requires very considerable effort
	High	Disassembly requires great effort (such as demolition of strong adhesive coatings)
	Medium	Demolition requires moderate effort (such as tearing up flooring)
	Low	Demolition requires little effort (such as removal of filler material)
	Very low	Very easily disassembled (such as clamped joints, loose supports, snapping or bolted joints)
Scope for disassembly	Unfeasible	Removal of material residues (e.g. screed, grout or sealants) on materials such as floor coverings or window frames. Separation procedures which cannot be carried out on-site.
	Feasible	Requires dedication of manpower and machines suitable for the sites: sanding, chipping, milling processes etc..

	Easy	Can be done manually by means of simple tools: lifting, pulling, uncovering (floors, wall coverings etc..)
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Source: DGNB (2014)

#### 4.2.1.3 Designing for future adaptability

The projected service life of a building is an important assumption in the modelling of the life cycle cost and environmental impacts of buildings. This is highlighted by both the EN 15978 standard for assessment of the environmental performance of buildings and the accompanying EN 15643-4 framework for the assessment of economic performance.

But it has also been highlighted that a buildings lifespan may end earlier than its potential design life because of market factors that make it obsolescent, hence the importance of future flexibility and adaptability to changing needs<sup>96</sup>. The IEA identified three main ways in which building designs can be made more adaptable:

1. More efficient use of space: More effective usage as occupiers needs change, for example as a business or family expands, which in turn may bring higher space utilisation;
2. Increased longevity: Extension of the total lifetime of a building, ensuring that this lifetime reflects the design life of components such as the structure. This will reduce the need to incur significant environmental impacts related to the construction phase.
3. Improved operational performance: Easier change over to new, more efficient technology as it becomes available. This could include technological innovations in lighting, heating, cooling, ventilation and energy generation. The average efficiency of many energy using technologies in buildings has improved by 20-100% in the last decade.

Addressing these design aspects does, however, carry a high degree of uncertainty and can therefore be challenging to consider alongside the immediate functional requirements of the client and/or prospective buyers and occupiers.

In this respect, adaptability can be broadly split into two types – adaption to the changing needs of occupiers over time, and adaption to changing demands in the property market over time.

##### 4.2.1.3.1 Adaptation to future occupiers' needs

Adaptation to occupiers' needs is a natural focus for clients for investment properties, as they will need to consider how to minimise voids and, where buildings and floors are sub-divided and let to different occupiers, meet their target yield or rate of return. A good example is the Dutch Real Estate Norm, which identifies location, site and building related factors and seeks to relate them to vacancy risk factors<sup>97</sup>.

This aspect of adaptability has also been the focus of attention for the so-called 'Open Building' movement in the Netherlands, as well as criteria and tools developed by the multi-criteria assessment schemes BREEAM and DGNB. Specialist office designers have identified the need to separate four 'layers' of a building, each of which have typical average lifetimes:

1. Shell: Superstructure, including façade if loadbearing (>50 year lifespan)

<sup>96</sup> International Energy Agency, *Assessing buildings for adaptability*, Annex 31 Energy-related environmental impacts of buildings, November 2001

<sup>97</sup> Real Estate Norm Netherlands Foundation (1992)

2. Services: Pipes, ducts, cables, machinery, lifts, escalators (15 year lifespan)
3. Scenery: Partitioning, ceiling, finishes (6 years)
4. Set: Furnishings, furniture, IT equipment (years to months)

Research and experience has shown that for office buildings, factors such as floor to ceiling heights and problems to adapt servicing such as electricity and air conditioning, which is generally located in the ceilings, can be major barriers to their conversion. The ease of replacement of the façade and major Heating, Ventilation and Air Conditioning (HVAC) plants are also major considerations, given the potential need to change the façade design, servicing strategy and to improve a buildings performance over time.

Changes in structural loads and the height and massing of a building are more technically challenging. Increases in the height of a building by adding additional structure, and assessment of the capacity of the existing superstructure and substructure to support the additional load, require careful technical assessment. This aspect of adaptability is addressed further in Section 4.2.1.3 in relation to structural design standards and is examined by the field studies in Section 4.3.

There could also be trade-offs as a result of flexible interiors and layouts. For example, independently arrangeable HVAC may mitigate against whole building natural ventilation and passive design. Flexible spaces could encourage more frequent refitting of offices. This is of potential life cycle cost and environmental significance because, as was identified in Working Paper 1, the fit-out and refurbishment of offices can be associated with significant impacts along the life cycle of a building. Figure 4.9 illustrates how fit out cycles can contribute to overall life cycle embodied CO<sub>2</sub> equivalent emissions.

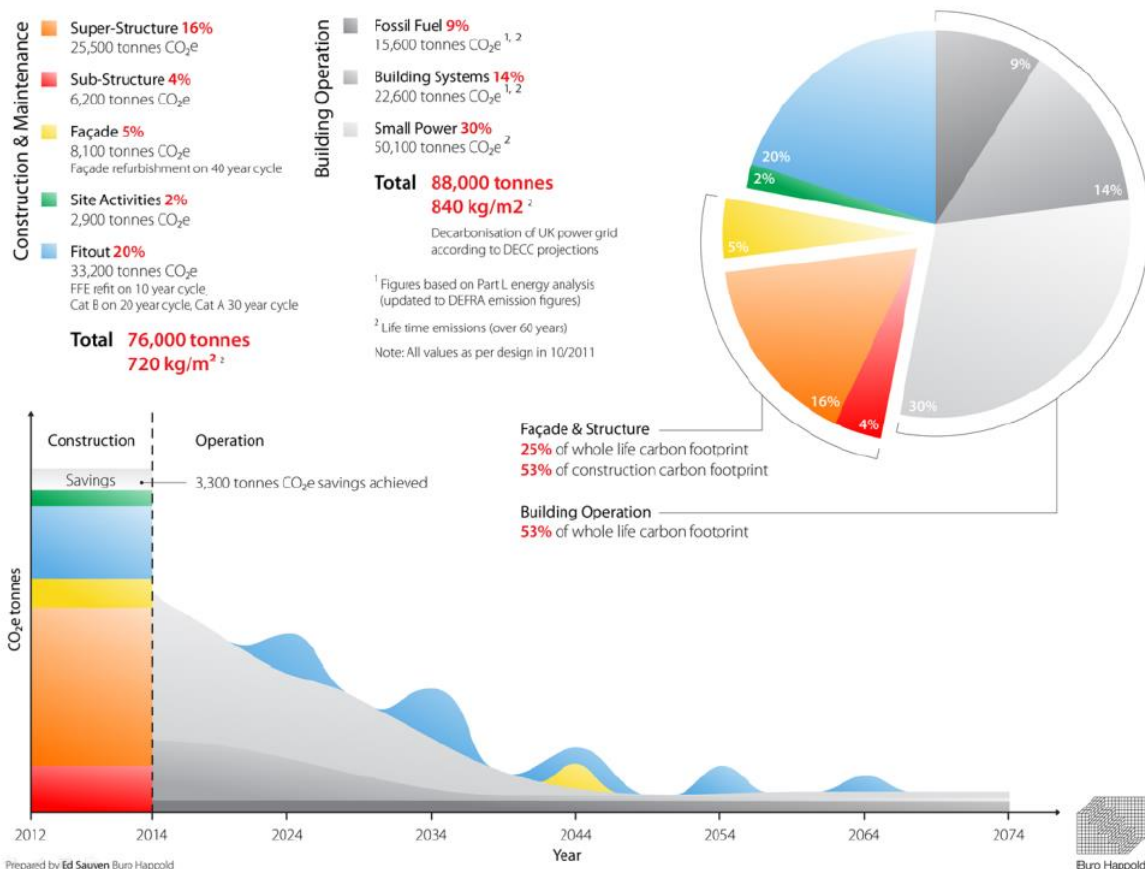


Figure 4.9 Indicative whole life CO<sub>2</sub> footprint for an office building in London

Source: Buro Happold (2014)

#### 4.2.1.3.2 Adaptation to changing demand in the property market

Adaption to changing demand in the property market is more challenging, as it supposes the potential for changes in the use class of a building. This could include conversions of offices to residential buildings, or vice versa. Constraints originating from residential building design and which may be difficult to remedy could, indicatively, include low ceiling heights and narrow structural bays.

#### 4.2.1.3.3 Identification of tools that quantify the potential for design for adaptability

The multi-criteria building assessment schemes BREEAM Netherlands and DGNB include tools that enable the physical 'flexibility and adaptability' of buildings to be quantified. These highlight factors to consider, including:

- The placement of columns and bay widths;
- The ease by which interior walls can be moved;
- The extent to which the building is divided into one or more parts or wings;
- The load bearing capacity of the floors;
- Plan depth and daylight penetration.

Factors such as these, sometimes also referred to as 'functional adaptability' aspects, should be considered at both the concept and detailed design stage, with reference to design criteria and tools that provide specific recommendations. A comparison of the calculation methods developed by BREEAM Netherlands and DGNB is provided in Table 4.7.

*Table 4.7 Comparison of the BREEAM Netherlands and DGNB adaptability calculation methodologies*

Aspect of methodology	DGNB	BREEAM Netherlands
Scope	Changes in occupier requirements and change in use	Changes in occupier requirements and change in use
Indicators	Seven in total: <ol style="list-style-type: none"> <li>1. Space efficiency</li> <li>2. Ceiling height</li> <li>3. Depth of floor plan</li> <li>4. Vertical access</li> <li>5. Floor layout</li> <li>6. Structure</li> <li>7. Building services</li> </ol>	Fifteen in total, split into three categories, each category with five indicators: <ul style="list-style-type: none"> <li>- Allotment (partitioning)</li> <li>- Adaptability (unit level)</li> <li>- Multifunctionality (building level)</li> </ul>
Weightings	Each can award a maximum of 10 points, with the exception of building services, which can award 40 points.	The three categories are weighted in a ratio of 5:11:15
Distinct aspects	<ul style="list-style-type: none"> <li>- Space efficiency factor</li> <li>- Depth of floor plan</li> <li>- Vertical service access</li> <li>- Potential to reconfigure water system</li> </ul>	<ul style="list-style-type: none"> <li>- Column placement</li> <li>- Façade pattern</li> <li>- Daylight access as proxy for depth of floorplan</li> <li>- E-installation connections and independence to arrange them</li> <li>- Specification of unit size</li> <li>- Fire resistance of building structure</li> </ul>

Source: BREEAM Netherlands (2014), DGNB (2014)

#### 4.2.1.4 Making the link between service life, adaptability and disassembly

There has been ongoing debate about the end of life stage for different building materials, particularly with regards to comparisons made between steel, concrete and timber. This debate has been stimulated by the inclusion in both EN 15804 and 15978 of life cycle Module D, which allows for 'benefits and loads beyond the system boundary' to be credited. The focus for Module D is therefore the re-use, recycling and recovery potential of materials.

As was highlighted in relation to macro-objective B1, consideration of the end of life phase for each major structural and façade material becomes important when end of life stage C1-4 and, in particular, module D are calculated.

Table 4.9 illustrates the potential adjustments to life cycle performance once module D is taken into account. It is important to note that these emissions factors are normalised to kg CO<sub>2</sub> e/kg material, so they do not take into account the mass of material required to achieve a comparable structural design performance or floor area.

Module D depends on assumptions being made about the recovery and recycling of building materials based on realistic present scenarios. Clear evidence of the potential for the deconstruction and disassembly of components, and potentially also their recyclability, would therefore complement this approach. Table 4.10 provides a set of indicative end of life scenarios, based on a UK context.

Table 4.9 Emissions factors for structural elements for the product stage (A1-A3), end of life stage (C1-C4) and benefits and loads beyond the system boundary (Module D)

Product	BS EN 15804 Modules			Total (kgCO <sub>2</sub> e/kg)
	A1-A3 (kgCO <sub>2</sub> e/kg)	C1-C4 (kgCO <sub>2</sub> e/kg)	D (kgCO <sub>2</sub> e/kg)	
Brickwork	0.16	0.01	-0.0207	0.15
Concrete blockwork	0.09	0.0103	-0.0053	0.10
C40 concrete	0.13	0.0043	-0.0053	0.13
C50 concrete	0.17	0.0037	-0.0053	0.17
Lightweight C40 concrete	0.17	0.0111	-0.0053	0.18
Hollowcore slab	0.2	0.0006	-0.0103	0.19
Hot rolled plate and structural sections <sup>1</sup>	1.735	0.06	-0.959	0.84
Hot formed structural hollow sections <sup>1</sup>	2.49	0.06	-1.38	1.17
Reinforcing steel <sup>1</sup>	1.27	0.061	-0.426	0.91
Steel deck	2.52	0.06	-1.45	1.13

Source: PE International (2014)

Table 4.10 Indicative comparison of demolition diversion routes and estimated diversion rates for concrete, steel and wooden construction materials (UK scenario)

End of life fate	Demolition diversion routes and estimated rates		
	Concrete	Steel	Wood
<b>Re-use</b>	<ul style="list-style-type: none"> <li>Structural concrete does not generally lend itself to re-use, mainly due to its continuous nature and the subsequent difficulties in separating components.</li> <li>There is some scope to re-use precast components</li> </ul>	<ul style="list-style-type: none"> <li>An estimated 5-13% of structural sections are re-used (2003)</li> <li>Sections are mainly re-used in warehousing and storage buildings</li> </ul>	<ul style="list-style-type: none"> <li>Most re-used structural timber is in the form of beams, joists and studwork.</li> <li>Salvaged timber is sometimes re-milled and sold to consumers in the form of timber flooring, beams and decking.</li> </ul>
<b>Recycling</b>	<ul style="list-style-type: none"> <li>Approximately 20% of crushed concrete from demolition sites is recycled as aggregate</li> </ul>	<ul style="list-style-type: none"> <li>94% is captured from construction demolition</li> <li>99% heavy framing products are captured or re-used</li> </ul>	<ul style="list-style-type: none"> <li>An estimated 23% of timber from UK demolition sites is recycled (BRE Green Guide)</li> <li>An estimated 10% of timber waste was used to make</li> <li>Chipboard (TRADA 2008) 13% is recycled to its original or equivalent use.</li> </ul>
<b>Downcycling</b>	<ul style="list-style-type: none"> <li>Cement is not possible to recover from concrete so it is generally broken up to be recycled as aggregate, hard core and/or fill</li> <li>Precast components can potentially be re-used</li> </ul>	<ul style="list-style-type: none"> <li>Steel scrap is manufactured into products with the same value as the original material.</li> </ul>	<ul style="list-style-type: none"> <li>A large proportion of timber waste is cycled back into products of lower value and utility.</li> <li>It is estimated that over 1 million tonnes of wood waste goes into the manufacture of chipboard (TRADA).</li> </ul>
<b>Incineration</b>	<ul style="list-style-type: none"> <li>Not applicable.</li> </ul>	<ul style="list-style-type: none"> <li>Not applicable.</li> </ul>	<ul style="list-style-type: none"> <li>It has been estimated that 6% is incinerated at end of life.</li> <li>Energy recovery is restricted by a lack of infrastructure.</li> </ul>
<b>Landfill</b>	<ul style="list-style-type: none"> <li>Increases in landfill tax have reduced the amount of concrete going to landfill in recent years.</li> <li>Diversion rates reached 77% in 2008</li> </ul>	<ul style="list-style-type: none"> <li>The amount of steel that ends up in landfill is a function of the ease of recovery.</li> <li>It is greatest for reinforcing bar, estimated at 6%, It is least for rolled sections, where a nominal 1% loss is assumed.</li> </ul>	<ul style="list-style-type: none"> <li>It is estimated that between 58-80% of timber from building demolition ends up in landfill (BRE Green Guide, TRADA)</li> <li>This may be due to the difficulty in separating timber with value from contaminated timber.</li> </ul>

Source: adapted from Building Design (2011)

#### 4.2.1.5 Reducing construction and demolition waste

In section 4.1 the EU policy priority to reduce construction and demolition waste was identified. This therefore requires a focus on waste that may arise from two distinct activities - building demolition to prepare a site and construction on-site for new buildings.

In seeking to address construction and demolition waste Hiete (2013)<sup>98</sup> highlights the overall importance of a systems perspective. Factors to address include:

- the development of area-specific supplies of materials;
- more thorough deconstruction processes;
- the need to address downcycling; and,
- assurance of the quality of recovered materials are identified.

The potential for assessment scheme criteria to affect change in the market is also highlighted.

The following sections briefly reviews supporting evidence as to how these waste flows from these two activities can be addressed and how performance improvements can be measured.

##### 4.2.1.5.1 Defining construction and demolition waste

A precise definition of Construction and Demolition Waste will be required to inform the development of any related indicators. Article 11.2 of the Waste Framework Directive<sup>99</sup> states that:

*(b) by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste (C&DW) excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.*

This definition excludes excavated material. The European Network of Construction Companies for Research and Development (ENCORD) waste measurement and reporting protocol reflects this definition by distinguishing between construction, demolition and excavation waste<sup>100</sup>.

From the reference year 2010 onwards, statistics on waste treatment introduced the treatment category backfilling. According to the Commission Decision 2011/753/EU backfilling is defined as:

*'...a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials.'*

Reporting on backfilling addresses concerns that instead of recycling or reusing materials back into construction products, they are being used as backfill on sites such as quarries and mines e.g. gypsum waste in Germany<sup>101</sup>.

<sup>98</sup> Hiete.M (2013) *Waste management plants and technology for recycling construction and demolition (C&D) waste: state-of-the-art and future challenges*, p.53-75 in Pachego-Torgal.F et al (ed)(2013) *Handbook of recycled concrete and demolition waste*, Woodhead Publishing Limited

<sup>99</sup> Waste Framework Directive 2008/98/EC

<sup>100</sup> ENCORD, *Construction Waste Measurement Protocol*, Version 1.0, May 2013

<sup>101</sup> BIO Intelligence Service, *Management of construction and demolition waste*, Final report for DG Environment (task 2), February 2011

#### 4.2.1.5.2 Addressing demolition waste

According to WRAP's Guidance on procurement requirements for reducing waste and using resources efficiently <sup>102</sup>, it is recommended that a Demolition Waste Management Plan is developed from an early stage including project-specific targets for total waste arisings and the amount of waste sent to landfill.

Excavation and backfilling operations are not to be taken into consideration in the best practices described within the European Commission's EMAS Reference Document on Best Environmental Management Practice in the building and construction sector <sup>103</sup>. WRAP also exclude backfilling from demolition waste reporting.

ENCODE, whose members include a range of EU construction companies, propose reporting on 'diversion rates' expressed in percentage terms. They propose rates of 80% for segregated waste sent off site, 100% for segregated waste which is classified as end-of-waste under the Waste Framework Directive and 50% for inert soil and stones that will be put to beneficial use (e.g. backfilling and restoration).

According to both technical literature and experience from Member States, a pre-demolition/strip-out audit allows for identification of the key building and infrastructure materials, which will arise from demolition and excavation works. The typical information provided by such an audit comprises:

- Identification and risk assessment of hazardous waste that may require specialist handling and treatment, or emissions that may arise during demolition;
- A Demolition Bill of Quantities with a breakdown of different building materials and products,
- An estimate of the % re-use and recycling potential based on proposals for systems of separate collection during the demolition process,
- An estimation of the % potential for other forms of recovery from the demolition process,

The following non-hazardous waste generated during demolition and strip-out works are suggested to be prepared for re-use, recycling and other forms of material recovery:

- Timber, glass, metal, brick, stone, ceramic and concrete materials recovered from the main building structures;
- Fit-out and non-structural elements, to include doors and their frames, flooring, ceiling tiles, gypsum panels, plastic profiles, insulation materials window frames, window glass, bricks, concrete in the form of blocks and precast elements, steel rebars.

The ICE Demolition Protocol goes further by making the link with new buildings that may be erected on the site. A New Build Recovery Index (NBRI) is defined as the percentage of materials from the demolition site to be procured in the new build and the potential for recycled materials to substitute for primary materials. The data is reported from the new building's Bill of Quantities.

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<sup>102</sup> WRAP Guidance Procurement requirements for reducing waste and using resources efficiently:  
[http://www.wrap.org.uk/sites/files/wrap/WRAP%20Construction%20Guide%20\\_FINAL.pdf](http://www.wrap.org.uk/sites/files/wrap/WRAP%20Construction%20Guide%20_FINAL.pdf)

<sup>103</sup> EC Reference Document on Best Environmental Management Practice in the building and construction sector (2012): <http://susproc.jrc.ec.europa.eu/activities/emas/documents/ConstructionSector.pdf>



#### 4.2.1.5.3 Permitting requirements to improve the quality of recovered demolition waste, Flanders region (Belgium)

Belgium has specific federal and regional regulations that seek to address material inventories and the mandatory sorting of both construction and demolition waste.

An asbestos inventory is compulsory for all demolition and refurbishment activities in which employees may be exposed. An inventory is required prior to the execution of works for every type of building (*KB 16/03/2006*)<sup>104</sup>. A material inventory is also required prior to demolition for buildings of more than 1.000 m<sup>3</sup> with a (partial) non-residential function (*VLAREMA 1/06/2012, art. 4.3.3*)<sup>105</sup>. This is not compulsory in the case of refurbishments and renovations. The inventory must include:

- a summary of the waste materials that will be recovered during demolition/dismantlement,
- data on the materials to be recovered, including:
  - an estimated quantity,
  - a description of the manner in which the waste materials (as described in *Vlarema art. 4.3.2*) will be selectively collected,
  - the storage and transport for the materials.

VLAREMA (1/06/2012)<sup>106</sup> obliges the separation at source of several waste streams. This includes the following fractions:

- rubble (stony fraction),
- materials containing asbestos (asbestos cement, ...),
- glass,
- wood debris,
- metal debris,
- discarded electrical and electronic equipment,
- batteries and accumulators and
- equipment/machinery containing ozone-decomposing substances or fluorinated greenhouse gases

Non-hazardous fractions that, in low concentrations, do not hamper recycling when combined with other fractions are generally not separated, generally for economic reasons (e.g. a low amount of glass in concrete rubble).

#### 4.2.1.5.4 Addressing construction waste

According to Osmani et al (2008)<sup>107</sup>, on average 33 % of waste generation from a construction site is the responsibility of a failure to implement waste prevention measures during both the design and preliminary construction phases. Additional causal factors highlighted included ordering errors during procurement, damage during materials handling and on-site operational practices.

A review of twenty-three published studies by Mália et al (2013) determined that for a new-build re-inforced concrete framed non-residential building the site waste arisings could be within a range of 48 and 135 kg m<sup>2</sup>. Concrete and brick generally accounted for approximately 70% of the overall waste volume generated. For all the types of non-residential building structure sampled, there was a range of 12 to 135 kg m<sup>2</sup> with a median of approximately 50 kg m<sup>2</sup>.

<sup>104</sup> KB 16/03/2006 regarding the protection of employees against the risks of exposure to asbestos

<sup>105</sup> *Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen*

<sup>106</sup> *Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen*

<sup>107</sup> Osmani, M., Glass, J., Price, A.D.F., 2008. Architects' perspectives on construction waste reduction by design. *Waste Management* 28, 1147-1158

The EMAS Reference Document on Best Environmental Management Practice in the building and construction sector <sup>108</sup> summarises data from waste generation at 603 construction sites between 2004 and 2010 for different building types provided by the UK Construction Resources and Waste Platform, 2009 <sup>109</sup>. As reported in Figure 4.6, average values are around 15 – 20 m<sup>3</sup> of waste per 100 m<sup>2</sup> (around 10 – 15 t/100 m<sup>2</sup>). Figures 4.10 and 4.11 provides a breakdown of the different waste typologies for different types of buildings. There are four main fractions of waste: bricks, concrete, mixed waste and inert fraction. The rest is composed of timber, packaging waste, metals and other minor quantities of other materials.

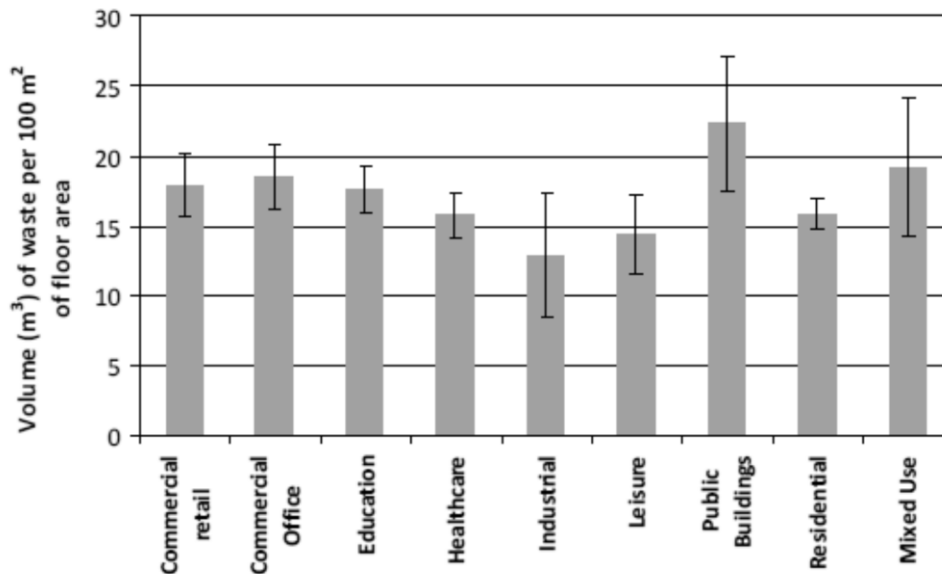


Figure 4.10. Waste generation during construction for different types of buildings  
Source: CRWP (2010)

<sup>108</sup> EC Reference Document on Best Environmental Management Practice in the building and construction sector (2012): <http://susproc.jrc.ec.europa.eu/activities/emas/documents/ConstructionSector.pdf>

<sup>109</sup> Construction Resources and Waste Platform, 2010. Benchmarks and Baselines 2009. Report, available at [www.wrap.org.uk](http://www.wrap.org.uk)

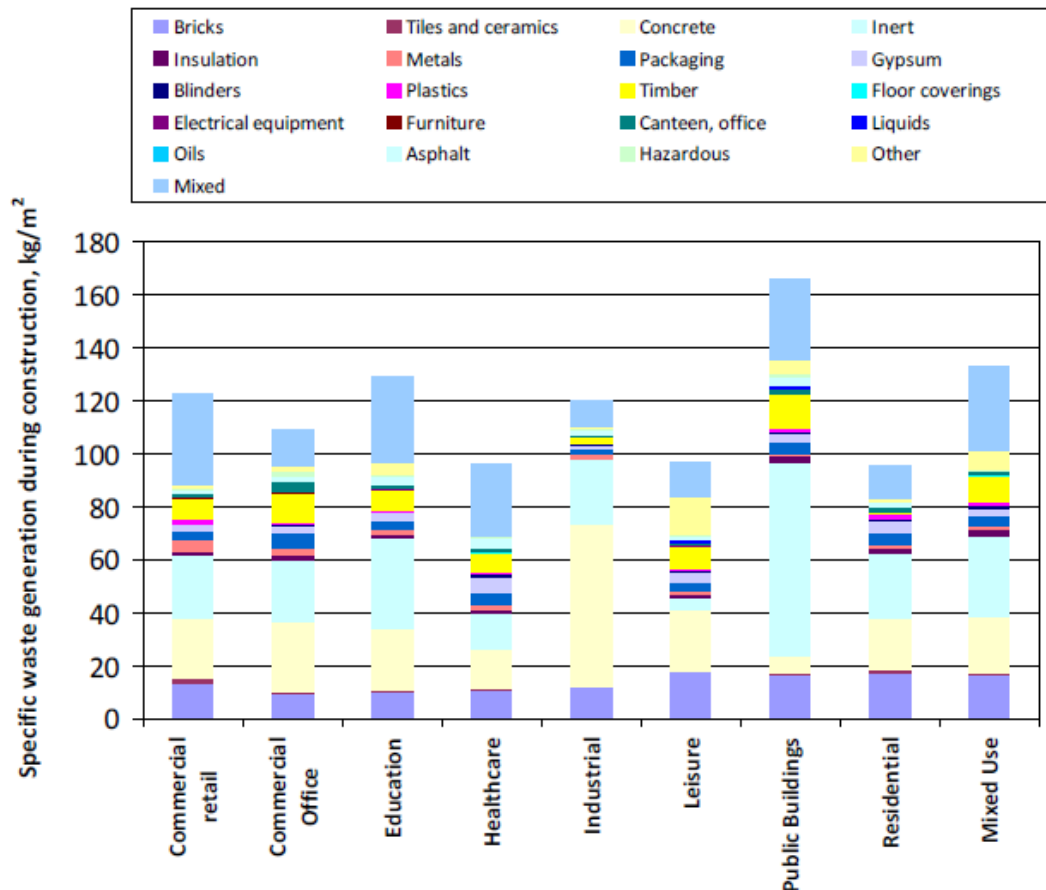


Figure 4.11 Waste generation per type during construction of different types of buildings (in volume and mass units)

Source: CRWP (2010) and European Commission (2012)

A site waste management plan (SWMP) is a commonly cited and widely practiced approach used in the construction industry to plan, monitor and implement actions to manage waste during construction. Such a plan is prepared prior to the commencement of work on-site. A site waste management plan usually consists of:

- A bill of materials ordered with estimates for waste arisings based on good practices, and the potential for waste prevention based on good practice;
- Estimates of the % re-use potential based on the use of segregated collection systems during the construction process;
- An estimation of the % recycling and recovery potential based on the use of segregated collection systems.

The UK provides access to extensive data and feedback from the implementation of SWMP's, having supported a number of best practice initiatives and enacted a legislative requirement between 2008 and 2013. In UK organisation WRAP's Site Waste Management Plans impacts survey 2009<sup>110</sup>, the results are presented of a stakeholders consultation on site waste management plans sent to over 800 contractors and clients in UK.

The survey aim was to identify the environmental and economic costs and benefits generated by using a SWMP. It has been highlighted that, if a SWMP is

<sup>110</sup> WRAP 2009: *Site Waste Management Plans impacts survey 2009*: <http://www.wrapni.org.uk/sites/files/wrap/SWMP%20Impacts%20Survey%20Final%20Report.pdf>

used properly, there can be significant benefits in terms of economic savings and project planning. The top actions identified in the survey were the prevention of waste through better design, waste segregation, recycling of waste produced and re-use of materials on site. Figure 4.12 provides an indication of how actions were implemented by the projects that formed part of the survey, as well as the extent to which they provided cost savings.

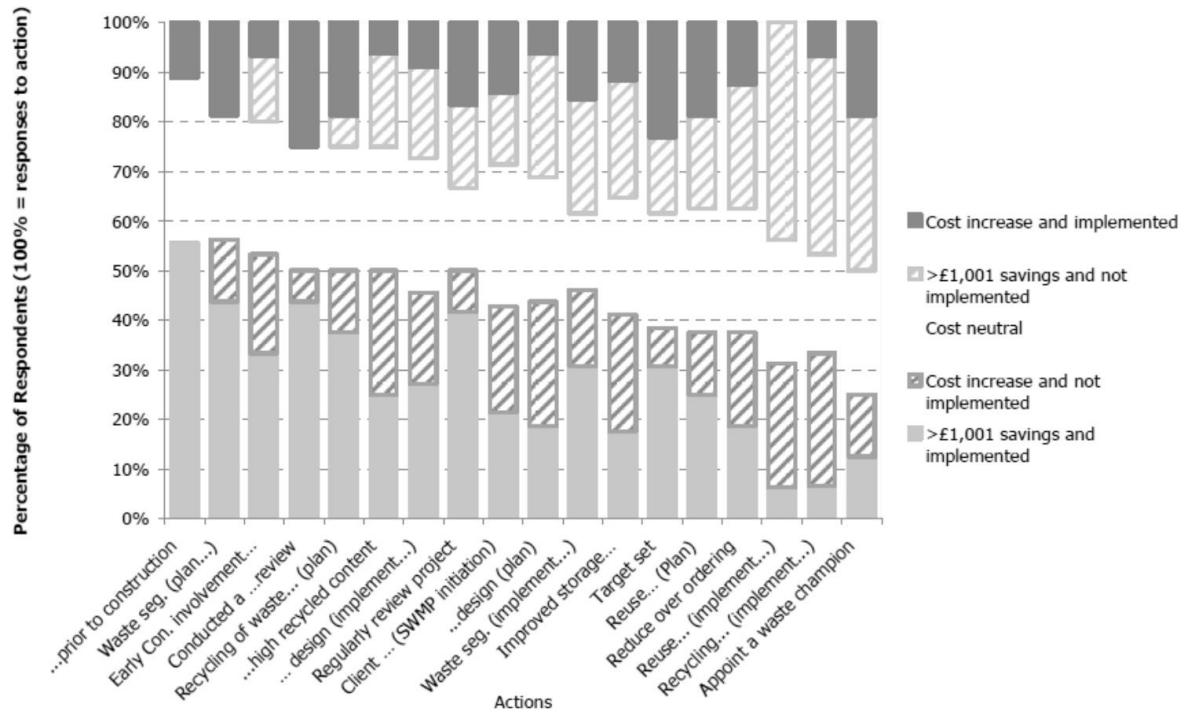


Figure 4.12 Elements of good practice (based on 19 completed projects)

Source: WRAP (2009)

In addition to SWMPs, a significant further strategy for reducing site waste is to use Modern Methods of Construction (MMC) or Off Site Manufacturing (OSM). The pre-fabrication of building elements, in part, or as whole in factories before being brought onto site can result in significant reductions in waste. This is because modern processes are more precise and controlled than on a traditional construction site.

Components and elements can also be manufactured to a precision that is difficult to achieve on site, supporting better construction quality, which can also have benefits in terms of energy efficiency. Table 4.11 summarises estimates made for the potential savings from different forms of MMC/OSM.

Table 4.11. Estimates of waste reduction through substitution of traditional with Modern Methods of Construction (MMC)

MMC	Est. % reduction	Level of confidence
Volumetric building systems	70 - 90	Reasonable
Timber frame systems	20 - 40	Broad estimate – depends upon the level of pre-fabrication
Concrete panel systems	20 - 30	Broad estimate
Steel frame housing systems	40 - 50	Broad estimate
OSB SIPS	50 - 60	Reasonable – depends on the level of prefabrication
Composite panels	20 - 30	Broad estimate
Pre-cast cladding	40 - 50	Broad estimate
LSF systems	40 - 70	Reasonable – depends on the level of prefabrication
Bathroom/shower & kitchen pods	40 - 50	Broad estimate
Pre-cast flooring	30 - 40	Broad estimate
Thin joint masonry	30 - 40	Broad estimate
Insulating concrete formwork	40 - 50	Broad estimate
Tunnel form construction	50 - 60	Broad estimate

Source: WRAP (2007)

## 4.2.2 Collaborative EU projects

A wide range of collaborative projects have been supported by the EU under ongoing programmes such as LIFE and Horizon 2020. It is not the intention of this study to provide an exhaustive review of lessons from this body of research. Instead, two recently initiated projects of direct relevance to macro-objective 2 have been identified and are briefly summarised.

These two projects relate to, or seek to build on, the experience gained from field studies examined elsewhere in this working paper, so they are considered useful in that they illustrate the 'state of the art' in terms of operationalising approaches to construction & demolition waste management that are likely to be required in order to create a more circular economy.

### 4.2.2.1 HISER and Tracimat

Tracimat is one of the activities of the European Horizon 2020 project HISER (Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste) <sup>111</sup>.

Tracimat is a construction and demolition waste (CDW) management organisation in Flanders (Belgium), founded by the Flemish Construction Confederation (VCB). The activity is relevant to this study because it focuses on improving the quality of materials derived from selective building demolition.

Tracimat will issue a "certificate of selective demolition" for construction and demolition waste that has been selectively collected and subsequently gone through a tracing system. The demolition certificate provides information whether the demolition waste can be accepted as "low environmental risk material" and therefore be processed separately from waste streams with a high environmental

<sup>111</sup> <http://www.hiserproject.eu/>

risk. Purer waste streams with a low environmental risk clearly have a greater upcycling potential.

#### **4.2.2.2 BAMP (Buildings as Material Banks)**

The aims of the BAMB project are the prevention of construction and demolition waste, the reduction of virgin resource consumption and supporting development of a circular economy through industrial symbiosis. The focus of the project is on building construction and process industries (from architects to raw material suppliers).

The BAMB-project seeks to implement the principles of the waste hierarchy. A key focus is to improve the value of materials used in buildings for recovery. This is achieved by developing and integrating two complementary value adding frameworks:

1. materials passports; and
2. reversible building design.

These frameworks will be able to change conventional (cradle-to-grave) building design, so that buildings can be transformed in order to fulfill new functions (extending their life span) or disassembled to building components or material feedstock that can be upcycled in new constructions (using materials passports). These aspects will be tested on a number of building pilots.

#### **4.2.3 Standards and harmonisation initiatives**

##### **4.2.3.1 A whole life cycle perspective on significant environmental impacts**

In the scope and definition of the macro-objective, reference was made to the potential to 'reduce significant environmental impacts' associated with building materials. The state of the art methodology to assess and identify significant environmental impacts is a Life Cycle Assessment (LCA).

Key standards that are used as reference points for building LCA are ISO 14040/44, EN 15978/15804 and the European Commission's Product Environmental Footprint (PEF).

In this section, the current market position and challenges relating to carrying out a full LCA for buildings is briefly reflected upon.

##### *The CEN/TC 350 standards series*

With the advent of the European single market for construction products, there was a concern that national Environmental Product Declaration (EPD) schemes and building level assessment schemes based on LCA principles would represent a barrier to trade across Europe. As a result, two standards were mandated by the European Commission to be developed by CEN/TC 350:

- EN 15804 (2012) <sup>112</sup> This standard provides the Product Category Rules for construction products and services, with the aim to ensure that EPDs for construction products, construction services and construction processes are derived, verified and presented in a harmonised way.
- EN 15978 (2011) <sup>113</sup> This standard deals with the aggregation of the information at the building level, describing the rules for applying EPDs in

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<sup>112</sup> EN 15804: 2012 + A1:2013. *Sustainability of construction works - Environmental product declarations – Core rules for the product category of construction products*

<sup>113</sup> EN 15978: 2011. *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*

a building assessment. The identification of boundary conditions and the setting up of scenarios are major parts of the standard.

The EN standards provide indicators for seven LCA Impact Categories taken from the LCA methodology CML and fifteen indicators relating to Life Cycle Inventory input flows - eight indicators for resource use, three indicators for waste and four indicators for output flows.

With the onset of the above referred to two EN standards, the major multi-criteria building assessment schemes are moving to harmonise life cycle criteria at building and product level – both in terms of supporting EPD schemes and LCA methodologies.

#### *The challenge of capturing a diverse range of environmental impacts*

A major challenge exists in seeking to make comparisons of building design options, given that each common building material is associated with distinct environmental impacts. As a result, a broad range of indicators would be required to capture all potentially significant impacts. Examples identified in Working Paper 1 included a range of products associated with a building fit-out or renovation - such as paint, ceramic flooring and tiles, window frames and copper pipe and wiring – which all have the potential to contribute to toxicity impact categories in the construction, replacement and/or refurbishment stages.

The CEN/TC 350 standards EN 15804 and EN 15978 provide a limited number of midpoint Impact Categories compared to the European Commission's Product Environmental Footprint (PEF) method, or the full set of midpoint Impact Category indicators provided by mature LCA methodologies such as CML or ReCiPe.

Whilst the impact categories listed by the CEN/TC 350 standards may be expanded in the future under an amended mandate from the European Commission to reflect methodologies developed for the PEF, they would not currently be able to support comparisons of, for example, the relative sustainability of forestry management or the ecotoxicity of material production processes.

#### *The challenge of interpreting and making useful comparisons of results*

Moreover, the absence of a robust, agreed common EU weighting methodology for Life Cycle Impact Assessment means that using the results requires expert judgement, and results can in general therefore only be used for broad identification of hot spots within individual Impact Categories *e.g. global warming potential, resource depletion potential, ecotoxicity*.

The PEF pilots have included normalisation and weighting steps, but the outcome of the overall process to develop Product Environmental Footprint Category Rules (PEFCRs), which is scheduled to run until earliest the end of 2016 <sup>114</sup>, must be awaited before conclusions can be drawn on how wider use of these steps may be promoted in the EU.

#### *Handling variability in data quality*

As was highlighted in macro-objective 2, there exist challenges relating to the data available to carry out an LCA for a building. Moreover, even if data is available its quality and suitability for: a specific building; the goal of the LCA (e.g. general comparison of design options, detailed analysis to optimise a design solution); and the geographical location may be poor.

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<sup>114</sup> European Commission, *The Environmental Footprint pilots*, DG Environment, [http://ec.europa.eu/environment/eussd/smgp/ef\\_pilots.htm](http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm)

For the Life cycle inventory generic and/or specific data can be collected. As a general rule, for foreground processes (*i.e. those directly relating to production of the building component*) specific inventory data should be used as far as possible. This data is typically compiled as primary data from the product/technology developer, goods producer, or service operator and should include specific secondary data from their tier-one suppliers (including waste service suppliers).

According to the EU ILCD Handbook <sup>115</sup> primary and secondary data sources are defined as follows:

- Primary data sources are the producers of goods and operators of processes and services, as well as their associations. Furthermore, it can be data collected and/or directly measured from the identified processes within the system.
- Secondary data sources are those which are either derived from primary data (possibly after re-modelling / changing the data) or from generic datasets *e.g. national databases, consultants, and research groups*.

Generic or average data may be more appropriate for processes of the foreground system in cases where the quality of available specific data is not considered sufficient. When this occurs, it must therefore be used where the generic or average data is considered sufficiently representative of the process.

In each case the equivalence or representativeness of data shall determine decisions as to whether to use producer-specific or average or generic data (Joint Research Centre 2010). In any case the process for collecting data and the choices made shall be transparent. Moreover, the data collection shall be well described in order to be transparent and ensure reproduce ability.

Furthermore, according to ISO 14044 the data has to meet specific quality requirements. These can be defined by several characteristics, such as:

- Time related coverage
- Geographical coverage
- Technology coverage
- Precision
- Completeness
- Representativeness
- Etc.

The way in which these general characteristics are dealt with in other LCA norms and methodologies. These are compared and contrasted in table 4.12.

#### *Semi-quantitative data quality evaluation*

These characteristics can be evaluated in a more general way *e.g.* according to the ISO 14044, or by a semi-quantitative assessment as presented in the European Commission's PEF guide. Such an approach may be introduced into the CEN/TC 350 standards under an amended mandate from the European Commission.

The PEF guide introduces a formula (1) that allows a semi-quantitative score to be derived from the aggregation of a number of qualitative assessments <sup>116</sup>.

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<sup>115</sup> Joint Research Centre (2010) *International Reference Life Cycle Data System – General guide for Life Cycle Assessment – Detailed guidance*, European Commission, First edition



$$DQR = (TeR + GR + TiR + C + P + M)/6 \quad (1)$$

Parameters:

- DQR : Data Quality Rating of the dataset
- TeR: Technological Representativeness
- GR: Geographical Representativeness
- TiR: Time-related Representativeness
- C: Completeness
- P: Precision/uncertainty
- M: Methodological Appropriateness and Consistency

Table 4.13 provides the data quality rating to be applied to each qualitative characteristic in order to convert it into a parameter. The levels are defined further in the PEF methodology.

*Table 4.12 overall data quality level according to the achieved data quality rating from PEF (European Commission – JRC, 2012)*

Overall data quality rating (DQR)	Overall data quality level
$\leq 1.6^{81}$	"Excellent quality"
1.6 to 2.0	"Very good quality"
2.0 to 3.0	"Good quality"
3 to 4.0	"Fair quality"
>4	"Poor quality"

<sup>116</sup> Joint Research Centre, 2012. *Product Environmental Footprint (PEF) Guide*. Deliverable 2 and 4A of the Administrative Arrangement between DG Environment and the Joint Research Centre No N 070307/2009/552517, including Amendment No 1 from December 2010, European Commission.

Table 4.13 Comparison of the data quality requirements for the ISO, EN and EU LCA standards and methodologies

Data quality requirements	ISO 14044	Product Environmental Footprint (PEF)	CEN/TC 350 standards series	
			EN 15804 (EPD PCR)	EN 15978 (building LCA)
<b>Overall data quality</b>	Data quality requirements should address the aspects identified in the following rows.	Calculation of the overall data quality by summing the quality ratings for each of the six quality criteria, divided by the total number of criteria. The Data Quality Rating (DQR) result is used to identify the corresponding quality level (see Table 4.12).	Check and rules defined for plausibility and compliance according to ISO 14044.	Data shall have been checked for plausibility and compliance with the rules of EN 15804.
<b>Time related coverage</b>	The age of the data shall not be older than ten years.	Qualitative assessment (TiR) that provides a parameter for overall evaluation by a semi-quantitative scoring.	According to the ISO 14044. In addition: <ul style="list-style-type: none"> <li>- Data shall be as current as possible.</li> <li>- Data sets shall be based on 1 year averaged data. deviations shall be justified.</li> <li>- Inputs to and outputs from the system shall be accounted for 100 years from the year for which the data set is deemed representative.</li> </ul>	According to the ISO 14044. In addition: <ul style="list-style-type: none"> <li>- Data shall be as current as possible.</li> <li>- Emissions from disposal processes shall be accounted for over at least 100 years <sup>117</sup>.</li> </ul>
<b>Geographical coverage</b>	Geographical area from which data for unit processes arises should be collected to satisfy the goal of the study	Qualitative assessment (GR) that provides a parameter for overall evaluation by a semi-quantitative scoring.	According to ISO 14044	The geographical coverage shall be representative of the region where the production is located.

<sup>117</sup> Emissions that occur beyond 100 years should be inventoried in a dataset as separate 'long-term' elementary flows and included in the impact assessment if relevant.

Data quality requirements	ISO 14044	Product Environmental Footprint (PEF)	CEN/TC 350 standards series	
			EN 15804 (EPD PCR)	EN 15978 (building LCA)
<b>Technology coverage</b>	Specific to the technology or technology mix.	Qualitative assessment (TeR) that provides a parameter for overall evaluation by a semi-quantitative scoring.	The criteria from ISO 14044 should be considered. The technological coverage shall reflect the real characteristics of the declared product or product group.	The technological coverage shall reflect the real characteristics of the declared product or product group.
<b>Precision</b>	Measure of the variability of the data values for each data expressed (e.g. variance)	Qualitative assessment (P) that provides a parameter for overall evaluation by a semi-quantitative scoring and that includes both precision and uncertainty..	According to ISO 14044	According to ISO 14044
<b>Completeness</b>	Percentage of flow that is measured or estimated	Qualitative assessment (C) that provides a parameter for overall evaluation by a semi-quantitative scoring.	According to ISO 14044	According to ISO 14044
<b>Representativeness</b>	Qualitative assessment of the degree to which the data set reflects the true population of interest.	<i>Addressed by separate qualitative parameters.</i>	According to ISO 14044	According to ISO 14044
<b>Consistency</b>	Qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis.	Qualitative assessment (M) that provides a parameter for overall evaluation by a semi-quantitative scoring.	According to ISO 14044	According to ISO 14044
<b>Reproducibility</b>	Qualitative assessment of the extent to which the methodology and data values would allow an independent practitioner to reproduce the results reported in the study	<i>The intention is that a set of overall Product Category Rules supports reproducibility.</i>	According to ISO 14044	According to ISO 14044

Data quality requirements	ISO 14044	Product Environmental Footprint (PEF)	CEN/TC 350 standards series	
			EN 15804 (EPD PCR)	EN 15978 (building LCA)
<b>Source of data</b>	The source of the data should be given.	Not evaluated as a data quality requirement.	According to ISO 14044	According to ISO 14044
<b>Uncertainty</b>	Uncertainty of the information shall be reported ( <i>e.g. data, models and assumptions</i> )	'Precision and uncertainty' are evaluated and incorporate in the P parameter (see Precision, above in this table).	According to ISO 14044	According to ISO 14044

#### 4.2.3.2 CEN/TC 350: Design for adaptability

EN 15643-3<sup>118</sup> includes reference to adaptability, defining it as 'the ability of the object of assessments or parts thereof to be changed or modified to make suitable for a particular use.' Moreover, it also states that the assessment of adaptability shall include the ability to accommodate:

- individual user requirements;
- the change of user requirements;
- technical changes;
- the change of use.

This standard is supported by the EN 16309 which is intended to provide calculation methodologies for assessing the social aspects of buildings<sup>119</sup>. The standard does not provide a quantifiable method as such, but emphasises the importance of specifying what adaptations shall be taken into account in any assessment. Moreover, it also provides a non-exhaustive list of potential aspects:

- Optimization of internal load-bearing-elements (columns, internal walls);
- Ease of demolition/demountability of internal building elements;
- Redundancy in load-bearing capacity;
- Accessibility/demountability of pipes and cables;
- Provision of space for additional pipes and cables required for a change of use;
- Provisions for possible future equipment (e.g. lifts).

#### 4.2.3.3 Development of the Sustainable Structural Design (SSD) methodology

The Joint Research Centre's Institute for the Protection and Security of the Citizen (IPSC) is responsible for the development of Eurocodes for structural design<sup>120</sup>. Eurocodes are a series of European Standards (EN 1990 - EN 1999) that provide a common approach to the design of buildings. They are the recommended means of ensuring conformity with the basic requirements of the Construction Products Regulation, as well as the preferred reference for technical specifications in public contracts.

JRC-IPSC have begun to develop a methodology combining environmental and structural performance parameters as part of a life-cycle approach - the Sustainable Structural Design (SSD) methodology<sup>121</sup>. It would place the emphasis on integrating environmental results in the structural performance, through the introduction of a simplified Performance-Based Assessment method. The method promotes the design principles of durability, probabilistic reliability and safety of structures, resulting in a quantified estimate at the design stage of the repair and downtime losses along the structures life cycle.

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<sup>118</sup> CEN, EN 15643-3 *Sustainability of construction works - Assessment of buildings - Part 3: Framework for the assessment of social performance*, Comite Europeen de Normalisation, January 2012.

<sup>119</sup> CEN, EN 16309 *Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology*, Comite Europeen de Normalisation, February 2014.

<sup>120</sup> Joint Research Centre, *The EN Eurocodes*, <http://eurocodes.jrc.ec.europa.eu/>

<sup>121</sup> Joint Research Centre (2014) *Building Design for Safety and Sustainability*, Institute for the Protection and Security of the Citizen, European Commission

#### **4.2.3.4 CEN/TC 250 Working Group (WG) 2: European Technical Rules for the Assessment and Retrofitting of Existing Structures**

The Joint Research Centre has published new European Technical Rules for the Assessment and Retrofitting of Existing Structures<sup>122</sup>. These have been developed by the CEN/TC250 Working Group (WG) 2 on assessment and retrofitting of existing structures.

An assessment of existing structures may be necessary in cases where they renovated or re-used. This may include where there may be a change in use or the addition of new floors or structures. A number of such examples are examined as field studies in Section 4.3. Such an assessment of an existing structure may be required in the following cases:

- Adequacy checking in order to establish whether the existing structure can resist loads associated with any anticipated change in use of the facility, operational changes or extension of its design working life;
- Repair of an existing structure, which has deteriorated due to time dependent environmental effects or which has suffered damage from accidental actions, for example due to impact, explosion, fire or earthquake;
- Doubts concerning the actual reliability of the structure;
- Rehabilitation of an existing building structure in conjunction with the retrofitting of the building services;
- Requirements from authorities, insurance companies or owners or from a maintenance plan.

The deterioration of an existing structure shall be taken into consideration. When deterioration of an existing structure is observed, the reliability assessment of the structure becomes a time-dependent deterioration problem as described in ISO 2394, and an appropriate analysis method shall be used.

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<sup>122</sup> Joint Research Centre, *New European Technical Rules for the Assessment and Retrofitting of Existing Structures*, Institute for the Protection and Security of the Citizen, European Union, 2015

## 4.3 Findings from investigation of the selected field study clusters

The macro-objective B2 field studies consist of the following seven clusters of buildings, each with a specific focus, which have been investigated by the JRC, VITO and ALTO Ingenierie:

- ALTO offices: new-build and residential (France and Luxembourg). Construction and demolition waste, design for deconstruction and disassembly, environmental impact assessment;
- ALTO residential: MacDonald masterplan (France). Construction and demolition waste, design for deconstruction and disassembly, environmental impact assessment;
- IRCOW project: Construction and demolition waste, design for deconstruction and disassembly;
- Ghandi/Hoogbouwplein: Design for adaptability, deconstruction and disassembly;
- Resource efficient structural design: Concrete structural systems (with support from the Concrete Centre, UK);
- Re-use and adaptability of structures: Steel structural systems (with support from Eurofer);
- Design for deconstruction and re-assembly: Circular buildings.

For each cluster the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

### 4.3.1 Cluster 1: ALTO offices – new build

#### 4.3.1.1 Background and context to selection of the cluster

*An overview of this ALTO building cluster is provided in Section 2.4.*

#### 4.3.1.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

A distinction is made between actions and improvements that relate to circular flows, material utility and significant environmental impacts.

*Circular flows*

#### **ZENORA**

Regarding site construction, the project achieved a diversion from landfill of 91.3% for a production of 3057 t of construction waste streams (initial target was set at 80%, see further). Achieving this target was not difficult in this project, as waste platforms in France are familiar with these criteria and associated indicators and as a result, have improved their activities and way of working to reflect this. However, this is still a challenge in places where buildings are not often certified.

#### **LAFFITE, LA MARSEILLAISE and CBKII**

The LAFFITE, LA MARSEILLAISE and CBKII projects are at design stage or in the beginning of construction but goals are set for construction waste: 80% of waste diverted from landfill (in weight) for LA MARSEILLAISE and 50% for CBKII. LEED certification requires a minimum of 75% for a maximum credit for waste diversion.

In LA MARSEILLAISE, specific LEED goals are set regarding circular flows. The LEED certification scheme gives credits for "recycled content". Credits can be achieved when materials are used that incorporate recycled materials (at least 10% or 20%). Furthermore, points are rewarded when regional materials are used. Hereby, LEED aims to reduce impacts from the extraction and processing of virgin materials and transport (LEED 2009 for commercial interiors). The project aims to achieve the recycling requirements for concrete, aggregates, carpet tiles and suspended ceilings. The concrete will reach the requirement for a regional material (more than 10% of the total cost of materials must be extracted and/or produced from a distance <800km).

#### *Material utility*

HQE requires the estimation of a building's lifespan and to design it accordingly. This is linked to environmental product declarations (EPDs), where the expected lifespan is detailed for building elements. The goal of this exercise is to list which elements will have to be replaced before end of life. It has to be kept in mind that values in EPDs are not always realistic and EPDs are not systematically verified by a third person. As a result, consequences on design are not strong. Reality also indicates that buildings are likely to be renovated before the usual declared duration of 50 years.

Regarding the adaptability of buildings and design to disassembly of building components, HQE requires a study in which aspects related to adaptability can be justified. However, HQE does not really specify what must be included in this study. As a result, projects often stress the fact that floor covering and suspended tiles are installed from a layout plan which enables adaptability of the building and the same reflection is done with other building systems (e.g. lighting). Moreover, the building plan considered a % of available power superior to the needs on HVAC aspects and spaces for cables are provided to permit evolution in the building. It can be noticed that integration of the tenant in the conception at an early stage can provide more credits on the global performance.

For the CBKII project, the German certification system DGNB was used to ensure adaptability. Here are some of the requirements for the DGNB certification:

- Indoor clearance height is greater than 2.75 m
- Non-load bearing, room-separating elements can be added to, converted, or removed without too much effort and with building operation continuing as normal (minimal limitations on operation )
- Non-load bearing, room-separating elements can be dismantled, and there is a possibility of temporarily storing unnecessary elements
- Power and media conduits run to easily accessible supply shafts, cable ducts, or false floors and/or are the lines visible
- Less than 80 % of the capacity of the supply shafts and ductwork for power and media conduits utilized
- Waste water removal/supply system's distribution and connections designed in such a way that they could be modified for other types of use

Moreover, the DGNB certification system uses the space efficiency factor ( $S_{\text{eff}} = \text{Usable floor area} / \text{Gross floor area}$ ) to determine the efficient use of floor area. To get a maximum score, the space efficiency factor must be at least 0.75. The  $S_{\text{eff}}$  cannot be maximized without limit. Legal requirements for the size of work areas and trafficked areas must be considered.

#### *Significant environmental impacts*

This aspect is considered in the 3 certifications concerned on this cluster. Unfortunately, credits have not been researched for LEED. As a result, there is no feedback on this certification scheme.



In the case of LA MARSEILLAISE, wood components will be PEFC <sup>123</sup> or FSC <sup>124</sup> certified in order to comply to HQE and LEED certification.

#### BREEAM (CBKII)

A technical study has been prepared in the design stage and provides a summary of the MAT 1 calculator, under the framework of the Green Guide<sup>125</sup> rating, which is part of BREEAM. This green guide allows the comparison of several materials and components.

The Green Guide rating covers the following impact categories: climate change, water extraction, mineral resource extraction, stratospheric ozone depletion, human toxicity, ecotoxicity to freshwater, nuclear waste, ecotoxicity to land, waste disposal, fossil fuel depletion, eutrophication, photochemical ozone creation, acidification.

#### BREEAM (ZENORA)

Four building elements have been studied using ELODIE as a nationally recognised LCA tool in France to evaluate their carbon footprint. For each building element, the solution with the lower environmental impact has been implemented in the development. Comparative analyses of a typical local building with the building assessed have been done with the Green Guide and the ELODIE LCA tool.

This report demonstrates that the outcome has influenced design choices for several building elements:

- external wall (choice for insulated concrete walls),
- upper floor slabs (choice for hollow core slabs),
- windows (choice for a mix of single and double skin façadas).

#### HQE (all buildings)

Environmental impact was analysed using the French EPD scheme – the FDES (Environmental and Health Declaration) <sup>126</sup>.

#### **4.3.1.3 How performance improvements were measured**

*Potential indicators identified were:*

- Waste arising during construction and/or demolition
- Material recovery ratio / Proportion of waste diverted from landfill
- An adaptability score
- Ease and scope of disassembly
- Knowing environmental impact of components

#### **4.3.1.4 Implementation experience of practitioners involved with delivery of the improvements**

LEED has not been achieved yet on LA MARSEILLAISE but the goal is to obtain the credits linked to environmental impact of materials.

Data is available for HQE and BREEAM requirements and even if some environmental data were not found for BREEAM Green Guide rating, BRE created a rating pretty quickly after our request. A Proforma procedure is planned for that.

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<sup>123</sup> <http://www.pefc.org>

<sup>124</sup> <https://ic.fsc.org/en/certification>

<sup>125</sup> <https://www.bre.co.uk/greenguide/podpage.jsp?id=2126>

<sup>126</sup> <http://www.inies.fr/accueil/>

The Green Guide and related BREEAM tools are user-friendly to use. ELODIE enables a higher score to be achieved in BREEAM but the conclusions reached as to the final design were the same on Zenora.

The BREEAM requirement to encourage and recognise the specification of 'responsibly sourced' materials for key building elements is very difficult to reach in France. Progress could be made but local bodies are not always able to provide the documentation required to meet BREEAM requirements (for instance, provision of an Environmental Management System certificate <sup>127</sup>).

Concerning the DGNB criterion linked to the space efficiency factor, this indicator illustrates an initial goal of the client regarding surface optimisation in the building. As a result, the certification did not directly imply a modification in the design project but the indicator might support clients to improve this aspect.

### **4.3.2 Cluster 2: ALTO offices – renovation**

#### **4.3.2.1 Background and context to selection of the cluster**

*An overview of this ALTO building cluster is provided in Section 2.4.*

#### **4.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

Again, a distinction is made between circular flows, material utility and environmental impact.

##### *Circular flows*

**EULER :** This building has been designed in order to recognize and encourage the in-situ reuse of existing building façades. As a result, more than 96 volume% of the façades have been reused. To reach an equivalent goal, the building has been designed in order to recognize and encourage the reuse of existing structures that previously occupied the site. As a result more than 96% of structure elements have been reused. Regarding site construction, a diversion from landfill of 91,3% was reached for a production of 3057 t of wastes.

**MEDERIC:** The building has been designed in order to recognize and encourage the in-situ reuse of existing building façades. As a result, more than 89% of façades have been reused. To reach an equivalent goal, building has been designed in order to recognize and encourage the reuse of existing structures that previously occupied the site. As a result more than 64% of structure elements have been reused. Regarding site construction, a diversion from landfill of 83% was reached for a production of 1788 t of waste.

**LAFFITE LAFAYETTE:** Regarding site construction, a diversion from landfill of 88,6% was reached for a production of 2954 t of waste.

As a result, it can be concluded that there are no real challenges on reusing structure or façade elements in renovation projects but it must be highlighted that those projects are all located in Paris and are linked to strict regulation regarding architectural conservation. Similarly, diverting wastes from landfill has been relatively easy to achieve but it should be noticed that this may depend on the location too: thanks to certification, waste platforms have improved their proposals and activity to respect the criteria and those indicators are familiar. This is still a challenge in places where buildings are not often certified.

##### *Significant environmental impacts*

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<sup>127</sup> <http://www.irca.org/en-gb/registration/schemes/Environment/>

This aspect is considered in the 3 certifications concerned on this cluster. Unfortunately, credits have not been researched for LEED as a result. As a result there is no feedback on this project.

### **BREEAM (EULER)**

BREEAM's MAT1 calculator is used, under the framework of BRE's Green Guide (the same approach as in new-build offices, see section 4.3.1). In the case of EULER, it should be noted that all existing / retained elements (e.g. external walls) have been allocated an A+ rating. (Ratings range from A+ to E in Green Guide's rating scale).

### **HQE (ALL)**

The tools, data and methodologies applied are similar as for new-build offices (see section 4.3.1)

#### **4.3.2.3 How performance improvements were measured**

*Potential indicators identified:*

- % of structure reused
- % of façade reused
- Waste arising during construction and/or demolition
- Material recovery ratio / Proportion of waste diverted from landfill
- Adaptability score
- Ease and scope of disassembly
- Knowing environmental impact of components

#### **4.3.2.4 Implementation experience of practitioners involved with delivery of the improvements**

The lessons learned are similar to those for the new-build office projects (see section 4.3.1).

### **4.3.3 Cluster 3: IRCOW project**

#### **4.3.3.1 Background and context to selection of the cluster**

IRCOW is a European project funded by the FP7 programme for the call ENV.2010.3.1.3-1 - Innovative technologies and eco design recommendations for reuse and recycling of Construction and Demolition (C&D) waste, with a special focus on technologies for onsite solutions. Thirteen partners from seven countries were involved (Belgium, Sweden, Poland, Spain, Italy, Germany and Finland), among which Tecnalía (coordinator) and VITO.

IRCOW developed and validated upgraded technological solutions to achieve an efficient material recovery from Construction and Demolition (C&D) waste by considering a life cycle perspective. The project developed new management schemes, separation technologies and products that are needed to significantly increase the reuse and recycling rates of C&W waste in the EU.

The technological solutions were tested in five in-field case studies: selective demolition of an industrial/service building in Spain, selective demolition of a school with wooden building components in Sweden, selective dismantling and on-site treatment of fibrous materials in Poland, demolition of office buildings related with construction of non-residential buildings in Spain and Belgium.

*Table 4.14 IRCOW FP7 project in-field case studies*

Building	Climate zone, Location	Typology	Type	Scale (m <sup>2</sup> )	Stage
CS1A	Southern Europe, Bilbao (ES)	Industrial building	Demolition	3,510	Demolition
CS1B	Southern Europe, Bilbao (ES)	Residential: Apartment block (student housing)	Demolition	2,540	Demolition
CS 4	Southern Europe, Teruel (ES)	Office: low-rise	Demolition, new-build	-	Demolition, construction
CS 5	Central-Europe, Antwerp (BE)	Office: low-rise	Demolition, new-build	-	Demolition, construction

#### 4.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

To reach the objective (resource efficient material life cycles), the project aimed at a high recovery rate of materials that can then be used in high-grade products (e.g. reuse or recycling) from demolition works. Therefore, the quality and purity of the recovered materials was crucial.

This quality, which was assessed by (time-consuming) manual classification techniques, is dependent on the demolition practices and/or subsequent sorting techniques. A selective demolition allows to obtain pure material fractions at the source. If necessary, mixed material fractions can be treated by sorting techniques (e.g. UV-VIS sorting) to obtain a high-quality material fraction.

These high-quality material fractions allow the development of high-grade construction products (e.g. structural concrete) with replacement of (part of) a primary material with recycled material. When certain material fractions (e.g. autoclaved aerated concrete) did not have enough recycling possibilities, the IRCOW project tried to develop products with these material fractions.

#### 4.3.3.3 How performance improvements were measured

The IRCOW project measured recovery rates of material streams during demolition and the amount of recycled material in the newly developed products. To evaluate the quality of the recovered materials, the composition was assessed by visual classification.

The recovery rates during demolition were compared to the target (70 m% recovery) of the Waste Framework Directive (2008/98/EC). This target was easily reached for the buildings that were studied in the IRCOW project (larger scale buildings).

#### 4.3.3.4 Implementation experience of practitioners involved with delivery of the improvements

The indicators are measurable if the necessary information is available. For the material recovery ratio of demolition works, the processing certificates of the involved recycling plants or landfills are necessary. However, these do not always give enough information and do not allow to differentiate between different recycling practices (details can differ between different countries).

The measurement of recovery ratios indicates that the WFD target (70 m% recycling of the non-hazardous fraction) can easily be reached for larger buildings that are mainly composed of stony material if a (semi-)selective demolition is performed. In the Flemish region, a recovery ratio of >90 m% is currently reached. The demolition of wood-based buildings can lead to lower recovery rates, since recovery routes for wood are not always well established and other fractions (e.g. insulation materials) can become more significant. Furthermore, small-scale demolition works or the lack of space can hamper selective demolition processes (e.g. the amount of container that can be placed).

A general recovery ratio does not make a distinction between high-grade or low-grade recovery. For product manufacturers, the quality of the recycled material is crucial. At the moment, quality is often assessed visually. This visual assessment is either time-consuming or inaccurate. Automated detection systems could facilitate this quality assessment (e.g. for concrete aggregates<sup>128</sup>).

#### 4.3.4 Cluster 4: Ghandi/Hoogbouwplein

##### 4.3.4.1 Background and context to selection of the cluster

The *Mahatma Ghandi district* is a social housing neighbourhood in Mechelen (Belgium). An architectural competition for renewal of the district was organized by the social housing corporation 'Woonpunt Mechelen' and three architectural offices were appointed to three zones: *KPW Architects* (zone 1), *Comodo* (zone 2) and *Jef Van Oevelen* (zone 3).

In this project the selective demolition of one of the apartment buildings was monitored and guidelines for Design for Change were developed. Design for Change is a design and construction strategy that acknowledges our continuously changing requirements and aspirations for the built environment. The aim of Design for Change is to create buildings that support change in a more efficient and effective way<sup>129</sup>.

Table 4.15. Overview of the two projects

Building	Climate zone, Location	Typology	Type	Scale	Stage
Ghandi district Zone 1	Central-Europe, Mechelen (BE)	Residential: apartment block	New-build	2 buildings, 51 units	Under construction
Hoogbouwplein	Central-Europe, Zelzate (BE)	Residential: apartment block	Renovation	1 building variable number of units	Post-design

##### 4.3.4.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

In this field study covering both housing projects, striving to 'resource efficient material life cycles' (cf. macro-objective B2) was not an explicit design objective

<sup>128</sup> Xia H., Bakker M.C.M., 2014. *Reliable classification of moving waste materials with LIBS in concrete recycling*. *Talanta* (120), 239-247.

<sup>129</sup> Debacker W., Galle W., Vandenbroucke M., Wijnants L., Lam W.C., Paduart A., Herthogs P., De Temmerman N., Trigaux D., De Troyer F. and De Weerd Y., *Design for Change: Development of an Assessment and Transitional Framework, End Report* (in Dutch), study commissioned by the Public Waste Agency of Flanders (OVAM), available through <http://www.ovam.be/veranderingsgerichtbouwen>

in the Gandhi district project (at least not in the early stages of the design), but more an outcome of the design and building strategy Design for Change.

Specific design recommendations regarding resource efficient material life cycles given by the research consortium for the Gandhi district project are:

- The reversibility of building elements and the possibility to reuse compound components can be increased by using building systems with (dry) reversible connections.
- The versatility of the building structure can be increased by integrating well-considered adaptable building elements within a multi-use frame structure.
- Application of the Design for Change strategy on the internal walls lead to different solutions. From an integrated environmental and financial life cycle approach, it has been recommended to apply adaptable, reusable wall components with dry connections for internal walls with a high expected frequency of adjustments. As a contrast, masonry walls were chosen for walls with a lower expected frequency of adaptation. (Paduart et al., 2013)

Experiences from the Gandhi project were used by KPW Architects to re-design the apartment building in Zelzate (Belgium), with the clear intention to use material resources in an optimal way over the service life of the building. Some specific improvement measures for the refurbishment of the apartment building were identified:

- Development of a "family tree" of compatible housing configurations. Thanks to this approach, KPW Architects became increasingly aware of the long-term consequences of their design choices.
- On strategic locations on each level of the building, multi-purpose co-housing rooms were envisioned. These rooms have either collective purposes (e.g. space for recreation, meeting or temporary stay of nursing personnel) or can easily be integrated to adjacent apartments to support changing individual user conditions (e.g. a growing family, or informal care of ageing dwellers)
- The existing building will be stripped to its bearing structure. Existing non-bearing internal walls will be replaced by new ones on a design grid, allowing prefabrication of internal walls, partition walls, and floor and ceiling elements.
- Based on the future scenarios and "family tree" of compatible housing configurations, adaptable, reusable wall components with dry connections are strategically selected for internal and partition walls with a high expected frequency of adjustments. This has been assessed by combining life cycle assessment (LCA) and life cycle costing (LCC).

#### **4.3.4.3 How performance improvements were measured**

*Key indicators identified regarding 'resource efficient material life cycles' are:*

- Compliance to a set of qualitative Design for Change criteria [unit: /]
- Initial environmental impact [kg impact-equivalent/m<sup>2</sup> NFA or external environmental cost in €/m<sup>2</sup> NFA]
- Life cycle environmental impact [kg impact-equivalent/m<sup>2</sup> NFA or external environmental cost in €/m<sup>2</sup> NFA]
- Initial financial cost [€/m<sup>2</sup> NFA]
- Life cycle financial cost [€/m<sup>2</sup> NFA]

The Design for Change assessment framework is widely applicable within the built environment and includes a qualitative and a quantitative part. The qualitative

part consists of a set of 23 practical Design for Change criteria on district, building and element level. To allow a systemic approach, all criteria are divided into 3 characteristics per level: i.e. the interfaces between components, the characteristics of those (sub) components and their composition (See Figure 4.13)

	Interfaces	Sub-components	Composition
Element	Reversibility Simplicity Speed	Durability Reused Compatibility	Pace-layered Independence Prefabrication
Building	Accessibility	Demountability Reusability Extensibility	Versatility
Neighbourhood	Clear Adaptable	Retrofitted Dimensioned Removable	Unified Multipurpose Diverse Densifiable

Figure 4.13 Overview of all 23 Design for Change criteria; a breakdown by scale (element, building, neighbourhood) and by theme (interfaces, sub-components, composition) makes it possible to establish a comprehensive and clear qualitative assessment of the design and construction of a building.

Once a set of design alternatives is selected, the environmental and financial characteristics of each alternative are quantified. The calculation of the initial and life cycle environmental impact (IE and LE, respectively) is based on the Belgian assessment method MMG<sup>130</sup>, in line with EN15978<sup>131</sup> and ILCD Handbook<sup>132</sup>.

Within the MMG method, environmental impacts are expressed in individual impact indicators (expressed in kg impact-equivalent/m<sup>2</sup> net floor area), but also as an aggregated indicator, based on external environmental costing<sup>133</sup>. The calculation of the initial and life cycle financial cost (IF and LF, respectively) is based on the Belgian Science Policy project SuFiQuaD<sup>134</sup>.

For the Hoogbouwplein project, (externalised) environmental and financial costs have been projected over time. In Figure 4.14 and Figure 4.15 fictive results for different internal wall options – each with an expected lifespan of 15 years in a building with an estimated life span of 60 years are shown. Separate graphs are used to present the environmental and financial results, as the results can sometimes be divergent and lead to different decisions being taken..Each shows

<sup>130</sup> Allacker K., Debacker W., Delem L., De Nocker L., De Troyer F., Servaes R., Spirinckx C., Van Dessel J. (2013), *Environmental profile of building elements*, study commissioned by the Public Waste Agency of Flanders (OVAM), available through

[http://www.ovam.be/sites/default/files/FILE1368696514672Environmental\\_profile\\_buildig\\_elements\\_LR.pdf](http://www.ovam.be/sites/default/files/FILE1368696514672Environmental_profile_buildig_elements_LR.pdf)

<sup>131</sup> CEN (2011), EN 15978 Sustainability assessment of construction works – assessment of environmental performance of buildings – calculation method

<sup>132</sup> Joint Research Centre (JRC) of European Commission (2011) - Institute for Environment and Sustainability (IES), International Reference Life Cycle Data System (ILCD) Handbook – Recommendations for Life Cycle Impact Assessment in the European context – based on existing environmental impact assessment models and factors. First edition.

<sup>133</sup> De Nocker L., Debacker W. (2014), Annex: Update monetisation of the MMG method, available through <http://www.ovam.be/sites/default/files/atoms/files/Annex-update-monetarisatie-MMG-2014.pdf>

<sup>134</sup> Allacker K., De Troyer F., Trigaux D., Geerken T., Debacker W., Spirinckx C., Van Dessel J., Janssen A., Delem L., Putzeys K. (2011), Sustainability, Financial and Quality evaluation of Dwelling types “SuFiQuaD”, Final Report, Belgian Science Policy, Research Programme Science for a Sustainable Development, Brussels, 107 p.

the cumulative increase in costs as the wall element is replaced successive times over a sixty year period.

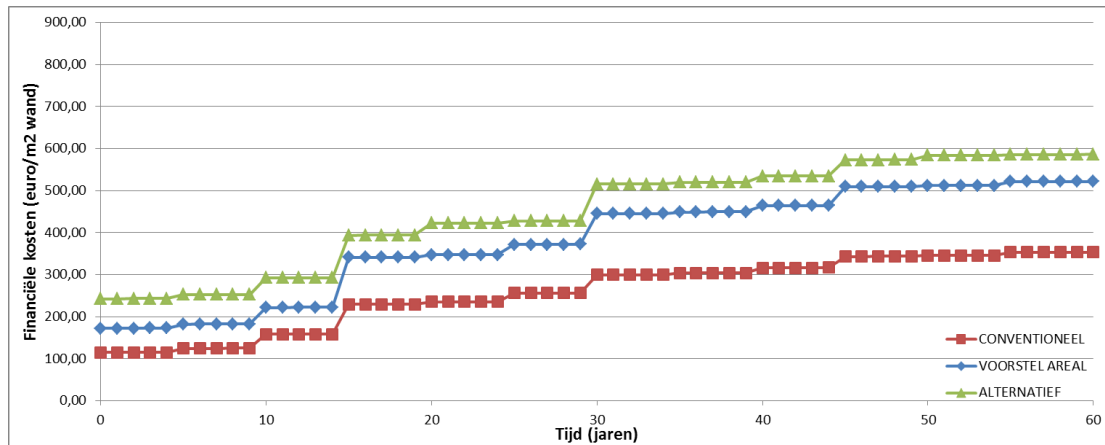


Figure 4.14 Financial costs in euro per m<sup>2</sup> of an internal wall over time, with an expected adjustment frequency of 15 years in a building with an estimated life span of 60 years.

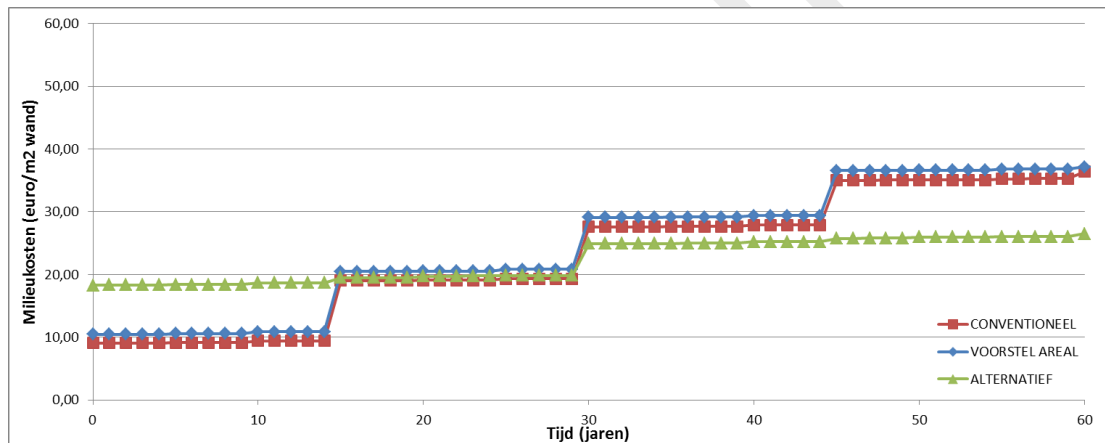


Figure 4.15 External environmental costs in euro per m<sup>2</sup> of internal wall over time, with an expected adjustment frequency of 15 years in a building with a estimated life span of 60 years.

#### 4.3.4.4 Implementation experience of practitioners involved with delivery of the improvements

Future consideration of the disassembly potential and transformation capacity of a building are new and difficult concepts for design teams and clients. There are no mature indicators to measure disassembly, reuse and the ability to easily change buildings. Nevertheless, some Design for Change principles have been used extensively in some niche building applications, such as light industrial buildings, warehouses and temporary exhibition spaces.

The Design for Change process and principles represent a state of the art technique when compared with other schemes. Furthermore, there are clearly links (and sometimes trade-offs) between Design for Change aspects (adaptability, disassembly, reuse etc.), environmental impacts and financial costs (LCC).

The twenty three Design for Change principles are a synthesis of design principles currently used by built environment designers - for example 'versatility',



'prefabrication' and 'durability'. Others, such as 'compatibility', 'pace-layering', 'reuse of existing (building) products' are only used by niche actors. After the completion of the described projects, the principles have been adopted by the building professionals involved (architects, engineering firms), but also by others to formulate pro-active guidance within Flanders region and across Belgium.

Although the calculations may seem complex, the efforts of the other designers were restricted to the provision of design configurations of the building and its elements, as well as initial financial costs for building products. This suggested that the effort was the same as in a traditional design process. The designers team were also interested to have an objective evaluation of their design choices.

### 4.3.5 Cluster 5: Resource efficient structural design (concrete)

#### 4.3.5.1 Description of the cluster

A number of different building projects from the UK are brought together where one of the key environmental benefits delivered was linked to the reduction in material use caused by decisions taken during the design stage with concrete structures. Basic details and images of the buildings are provided below.

Table 4.16 Basic details of the selected building projects

Building	Climate zone, Location	Typology	Type	Scale	Stage
University of Sheffield, Information Commons, Ramboll UK.	Central Europe, Sheffield (UK)	Office and educational: Medium-rise	New-build	7700m <sup>2</sup> 7 storeys	In-use
160 Tooley Street, Arup / Lang O'Rourke	Central Europe, London (UK)	Speculative Office Medium rise	New-build	18500m <sup>2</sup> 6 storeys	In-use
240 Blackfriars, London, Great Portland Estates	Central Europe, London (UK)	Speculative Office High rise	New-build	ca. 20450m <sup>2</sup> 19 storeys	In-use
One Coleman St, London, Arup	Central Europe, London (UK)	Office, High rise	New-build	16700m <sup>2</sup> 10 storeys	In-use

#### 4.3.5.2 Background and context to selection of the cluster

Each of the projects highlights in one way or another how the design of a concrete structural frame can deliver virgin/total material savings, an increase in spatial efficiency and/or improved cooling performance of the building.



Figure 4.16 The four identified field studies a) One Coleman Street, b) 160 Tooley Street, c) Sheffield University Information Commons and d) 240 Blackfriars.

Only the One Coleman Street and Sheffield projects actually had a core focus to reduce virgin material quantities in the structure. The other projects looked to use the structural components to partially save on temporary formwork during construction and avoid the need for suspended ceilings (and the materials that go with that) during the use phase.

The benefits for each project relate to one or more of the points below:

- The use of lighter concrete floor slabs via void formers (Sheffield).
- The use of thinner floor slab sections via post-tensioned concrete (Tooley St. and Blackfriars).
- Using pre-fabricated and exposed structural components to minimise the need for formwork, fit out materials and follow on contractors (Tooley St. and Blackfriars).
- The partial replacement of cement and aggregates in concrete by recycled or secondary materials (One Coleman St.).

#### 4.3.5.3 Translation of the macro-objective into actions and improvements by buildings in the cluster

Of the four main macro-objective 2 aspects (lean construction, circular flows, waste minimisation and adaptability) that have been identified as being relevant, the field studies in the cluster cover lean construction and circular flow aspects only. Clear examples of translating the macro-objective into actions include:

- Specifying precast voided concrete slab bases for floor slabs with specialist suppliers.
- Use of self-compacting concrete, clean (shot-blasted if necessary) steel moulds, final sandblasting of precast pieces if necessary and careful

handling and storage onsite of precast fair-faced structural elements to maximise the quality of finish and reduce potential for surface damage.

- Preliminary trials with all pre-cast concrete specified with pre-cast mixes and moulds to ensure that surface quality requirements can be met.
- Specification of thinner, post-tensioned floor slabs (e.g. 270mm) instead of conventional reinforced slabs (350mm).
- Sourcing of secondary aggregates (e.g. stent) and supplementary cementitious materials (e.g. fly ash) to replace virgin aggregates and Portland cement respectively.
- Preliminary trials with concrete with different blends of secondary aggregate and fly ash to ensure that minimum setting time, slump/workability and early strength requirements can be respected.

The importance of these actions was highlighted in desk research and interviews conducted with relevant construction professionals who were involved in these projects.

#### 4.3.5.4 How performance improvements were measured

Most of the field studies did not actually claim a specific saving of material compared to a reference benchmark building design or only claimed improvements compared to a conventional structural component (i.e. voided slabs versus conventional concrete flat slabs).

The clearest example of material reduction measurements was the use of lightweight Cobiax floor slabs in the Sheffield University Information Commons building (see Figure 4.17).

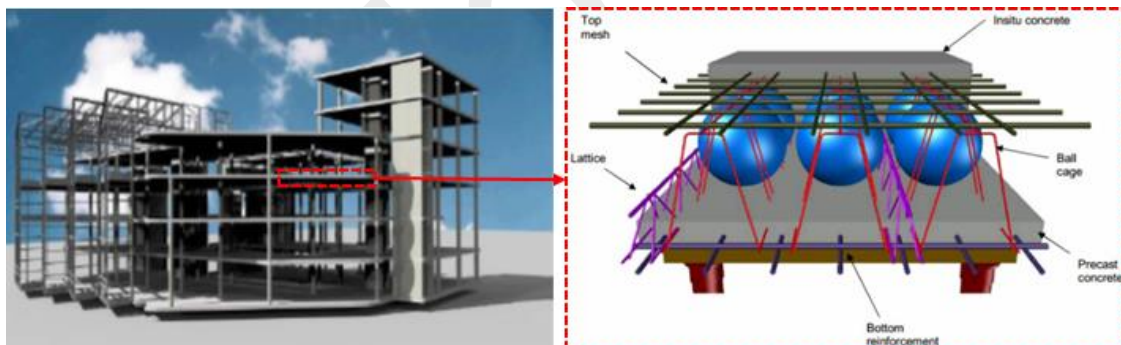


Figure 4.17 Example of a Cobiax floor slab cross-section (right) as used in the Sheffield University Information Commons structure (left).

Most of the material savings were already stated by the supplier (Cobiax) who claims that reductions in concrete of 35% and reinforcement steel of up to 20% are possible together with weight reductions of up to 35% compared to conventional reinforced slabs. On the actual building in Sheffield, due to only partial use of Cobiax in the roof and core areas and its non-use in the ground slab, concrete savings for slab concrete were actually lower (around 26%). If all other concrete used in the building is included in the calculation, then the total savings were around 14%. The actual deadweight reduction was not accurately calculated but an approximate figure of 30% was used as an estimate.

With 160 Tooley Street, the use of thinner post-tensioned slabs and exposed ceiling soffit structure with integrated cool air diffusion through raised floors was integrated into thermal modelling and predicted to deliver a 20-30% in energy consumption for heating and cooling. Although there are also associated material

savings for avoided fit-out materials like suspended ceilings, cladding and plasterboard, only cost and energy data were reported.

With the 240 Blackfriars building, the combination of using thin, 270mm post-tensioned floor slabs with exposed concrete soffit ceilings were calculated to generate enough vertical space savings to turn a 17 floor building into a 19 floor building while respecting the same 2.7m floor to ceiling height within the same structural frame. Given that the total office floor space is stated as 220,000 sqft, dividing this evenly by 19 floors and multiplying by the original 17 floors translates to an original floor area of almost 197,000 sqft and thus an estimated increase in spatial efficiency of almost 12% simply brought about by the use of thinner floor slabs and exposed soffit ceilings.

With One Coleman Street, considering recycled steel in rebar, fly ash used in cement and china clay waste (stent) used as aggregate, the overall recycled content in the structural concrete used reached 50% by mass and 70% of the cost of the structure.

#### **4.3.3.5 Implementation experience of practitioners involved with delivery of the improvements**

##### *Cross-cutting feedback*

Feedback generally revealed that although quantitative material data is clearly available for building projects, this is never reported as any kind of performance indicator based on current practice or even in projects working towards certification. Since the global recession, there has been a general shift back towards standard structural designs and practices. When attempting to sell "material efficient" designs, it is necessary for another direct tangible benefit to be associated with it, such as reduced capital cost, reduced construction time/risk or reduced operational energy demand (i.e. use phase cost).

A stronger encouragement from building assessment schemes could potentially stimulate material efficient thinking in terms of delivering structural solutions with lower embodied CO<sub>2</sub>, although using structural solutions with fewer materials does not necessarily imply a reduction in embodied CO<sub>2</sub>.

##### *Project specific feedback*

In the case of the Sheffield University project, the lack of previous experience in the UK with Cobiax floor slabs was a major sticking point for the client, who was reluctant to underwrite the preliminary work necessary for this project. The use of Cobiax balls resulted in a minimum slab depth of 340mm when in fact a conventional design would have been 325mm. So in this case, there was a slight trade-off between light-weighting the structure and losing floor to ceiling clearances.

However, this project was completed in 2007 and since then more vertically compact void formers have become available that permit slab depths as thin as 200mm. The design solution delivered for concrete volume and dead load reductions helped comply with the required load allowance of +5kN/m<sup>2</sup> which is of added importance in this site where the movement of bookshelves can cause changes in dynamic loading.

With the Blackfriars and Tooley St projects, the obvious benefit of post-tensioned slabs and exposed concrete soffits for clients were increased floor to ceiling clearances, exposed thermal mass to regulate temperature and improved spatial efficiency in high-rise buildings. Designers focussed mainly on promoting savings in heating and cooling energy requirements rather than on material savings caused by avoided fit-out materials. The actual environmental benefits from post-tensioned concrete are not so clear-cut when compared to conventional concrete because the 10-20% savings in actual concrete volume can be partially or fully

offset by an increase in cement content (i.e. from 400 to 500kg/m<sup>3</sup>). So there is a potential trade-off with lower concrete volumes versus high cement contents.

When considering the One Coleman Street project, it is worth remembering that there is a large inertia amongst structural engineers to incorporate any recycled content into structural concrete. The minimum early strength, workability and shrinkage characteristics of concrete can be affected by relatively small changes in composition and structural design. Due to its fundamental importance from technical and safety perspectives, structural engineers have always been relatively conservative compared to other professions within the construction industry.

The key to the success of incorporating large quantities of recycled aggregate (stent from clay quarrying) and supplementary cementitious material (fly ash) was liaising directly with the suppliers of these secondary materials and conducting in-depth quality control tests and preliminary trials to be sure that the novel design mixes would deliver the necessary performance. Careful analysis of the structure to identify which parts are in least need of providing high early strength was also used as a means to prioritise components where higher recycled contents could be achieved.

### 4.3.6 Cluster 6: Resource efficient structural design (steel)

#### 4.3.6.1 Description of the cluster

A number of different building projects from the UK are brought together where one of the key environmental benefits delivered was linked to the reduction in material use caused by decisions taken during the design stage with concrete structures. Basic details of the buildings are provided below.

Table 4.17 Basic details of selected building projects

Building	Climate zone, Location	Typology	Type	Scale	Stage
6 Pancras Square	Central Europe, London (UK)	Office: Medium-rise	New build	37,000m <sup>2</sup> 11-13 storeys	Completed 2015
Vulcan House	Central Europe, Sheffield (UK)	Office Medium rise	New build	13650m <sup>2</sup> 7 storeys	In-use
Media City	Central Europe, Manchester (UK)	Mixed use, Hotel/office High rise	New build	18625m <sup>2</sup> 17 storeys	Phase I completed
One Kingdom Street	Central Europe, London (UK)	Office High rise	New build	33018m <sup>2</sup> 10 storeys	In use

#### 4.3.6.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

All four of the main aspects of macro-objective B2 (lean construction, circular flows, waste minimisation and adaptability) can apply to buildings with steel framed structures just as much as it can with other structural materials:

- Logging of all materials/wastes brought onsite and taken offsite.

- The use of larger structural grids and longer spans of structural sections to maximise the open indoor space or small planning grids to increase flexibility in closed room layouts.
- Integrating services into the structural beams to optimise use of space and maintain adaptability of internal spaces and reduce steel quantities used in beams.
- Use of thin suspended ceilings or floor slabs to optimise floor to ceiling clearances within a given structural frame.

#### **4.3.6.3 How performance improvements were measured**

Both 6 Pancras Square and Vulcan House make use of cellular steel beams to integrate mechanical and electrical services and deliver them across the building. Details from the 6 Pancras Square project found that choosing deeper cellular beams with services integrated instead of equivalent strength solid web beams reduced steel content in the beam by 25-35 kg/m, equating to savings of 400-550 tonnes of steel across the entire 6 Pancras Square building.

The Vulcan House project used a total of 980 tonnes of structural steelwork on a 9m by 15m primary structural grid in order to maximise column free spaces. A total carbon footprint of materials brought on site was calculated by logging all the materials brought onsite as well as where they had come from and the transport mode used. Waste arising from excavation was minimised by the use of piled solution instead of concrete pads in foundations although the exact savings were not provided.

The use of composite concrete/profiled metal deck was used to deliver thin, 150mm suspended floors.

With the One Kingdom Street and MediaCity projects, the cost and carbon footprint of structural solutions were reported on £/m<sup>2</sup> GIFA and kg CO<sub>2</sub>eq./m<sup>2</sup> respectively. These were reported for the following three levels: frame and floors; substructure and total building.

#### **4.3.6.4 Implementation experience of practitioners involved with delivery of the improvements**

##### *Cross-cutting feedback*

Due to the cost of steel, structural engineers are naturally inclined to try to reduce the quantities of steel to a minimum. Although quantities can be reduced by specifying lighter beams for those parts of the structure subject to lesser loads and forces, this would not necessarily translate into cost savings and the continued use of standard sized beams throughout to reduce complexity in design calculations and the subsequent construction programme is likely to continue, even in "green" projects.

##### *Project specific feedback*

From the Vulcan House and Pancras Square projects, the potential advantages in material savings afforded by the use of cellular beams was clearly demonstrated and is likely to be widely used in similar future projects.

Regarding the use of carbon footprinting with structural solutions, it was highlighted that a clear methodology must be stated that fits within the EN 15804 framework, explains what life cycle stages are included (i.e. modules A-D) and links to the specific or generic data used. Comparability can be improved by using the same tool. When comparing results from different tools, the scope and boundaries and any other potential sources of variation must be considered.

Consequently, there is a real value in having the actual material quantities used as a basis for all calculations and for keeping this basis as transparent and transferrable as possible. When comparing the environmental impacts of different structural solutions, it was strongly recommended that any indicators be expressed on a per m<sup>2</sup> basis and not on a per kg basis.

### 4.3.7 Cluster 7: Re-use and adaptability of structures

#### 4.3.7.1 Description of the cluster

The selected field studies are all examples of where the existing structure of a building has been largely retained during major refurbishment projects and associated environmental benefits reported. They illustrate how the relative merits of doing this should be judged on a case by case basis, accounting for site specific factors, the condition of the existing structure and the aspirations of the client.

Table 4.18 Basic details of selected building projects

Building	Climate zone, Location	Typology	Type	Scale	Stage
Elizabeth II Court, Ramboll UK.	Central Europe, Winchester (UK)	Office: Medium-rise	Refurbishment	13600m <sup>2</sup> 7 storeys	In-use
55 Baker Street, Make, Expedition	Central Europe, London (UK)	Office Medium rise	Refurbishment	56000m <sup>2</sup>	In-use
Park Hill, Urban Splash	Central Europe, Sheffield (UK)	Residential High rise	Refurbishment	Around 900 flats Up to 13 storeys	Phase I completed



Figure 4.18 Example of before and after of refurbishment projects at 55 Baker Street (left) and Park Hill (right).

#### 4.3.7.2 Background and context to selection of the cluster

Each of the buildings in the cluster involve the reuse of concrete frame structures from buildings that have been around since the 50's and 60's. These buildings form part of a huge, post-World War II building stock across Europe which will be coming to a stage in their life and where developers will be thinking about whether to demolish and build from new or to refurbish.

#### **4.3.7.3 Translation of the macro-objective into actions and improvements by buildings in the cluster**

All of the actions for improvement involve decisions taken at the design stage and relating to structural materials. Clear examples of translating the macro-objective into actions include:

- Careful analysis of the existing structure for weak points, structural integrity and signs of visible damage.
- Evaluate reuse of existing structure in the context of client brief and aspirations (use changes, daylighting, open spaces etc.) and devise a targeted demolition plan if necessary.
- Look at ways to incorporate any new structural elements to reinforce the existing structure and/or to deliver new client driven requirements or “green” performance (e.g. extra floor space, exposed thermal mass, ventilation pathways, daylight, airtightness and insulation of building envelope) that marry with the existing structure.

#### **4.3.7.4 How performance improvements were measured**

The Elizabeth II Court project was unique in the sense that the refurbishment of the building was part of a centralisation exercise where staff from departments in other locations would be brought together in the refurbished building, releasing finances that were tied up in leasing other buildings. Due to the increased number of staff to be located at the site (from 625 to 1100 – a 70% increase), spatial efficiency of the office layout was of paramount importance and attempts to optimise energy and water consumption were also prioritised.

Spatial efficiency was therefore calculated by dividing the number of employees (1100) by the total surface area of the existing building and other leased buildings/offices. The net result was an increase of 30% in occupant density (occupants /m<sup>2</sup>). The environmental benefits of reusing the existing frame were expressed as % embodied energy of an equivalent new building (a 50% reduction in embodied carbon was claimed). Energy efficiency was calculated in terms of kg CO<sub>2</sub>eq./m<sup>2</sup>/yr (a 70% improvement was calculated in the refurbished building).

With the 55 Baker Street building, the reuse of the existing structure was expressed as % reused (uncertain if that was by volume, mass or area). The total floor area of the building before and after refurbishment was calculated and increased by 30%.

With the Park Hill project, the unique condition is that the existing building is Grade II listed, which greatly complicates any attempts to demolish or significantly alter the structure. Planning permission was granted so long as the existing concrete frame was kept as is although the remainder of the building was stripped out. As the project is still ongoing, final results have not been communicated.

#### **4.3.7.5 Implementation experience of practitioners involved with delivery of the improvements**

##### *Cross-cutting feedback*

In general for all three projects, clear material, cost and carbon savings were evident by reusing the existing structure. There were general cost benefits too compared to building a similar new building although the upfront design and assessment work was more challenging and depends upon how clear or how flexible the client brief is.



### *Project specific feedback*

The Park Hill project has some unique challenges due to the fact that the original structure (Grade II listed) and its impact on the appearance of the buildings must remain. Potential issues with thermal bridging must be overcome if the building is to achieve good energy performance levels that exceed the UK Building Regulations Part L.

On the other hand, when restrictions on the structure are not imposed, the Elizabeth II Court project is a clear example of how a structure can be modified to deliver improved working spaces, spatial efficiency and energy performance. The latter was calculated at 28kg CO<sup>2</sup>/m<sup>2</sup>/yr. The floor plates were used to passively draw air from the internal courtyard across the building and out the external faces. Locally sourced bricks and sustainable certified timber were used to improve the buildings external appearance to better fit with its surroundings. The client has reported high levels of occupant satisfaction.

With 55 Baker Street, the environmental benefits of the refurbishment option were expressed in various different ways including: prevention of 35,000 tonnes of concrete demolition waste being generated; avoiding addition embodied energy equivalent to that used by 11,000 homes for one year and saving CO<sub>2</sub> emissions equivalent to 2,500 cars over a one year period. Without knowing the assumptions behind these figures, i.e. "*What is the annual CO<sub>2</sub> emission of a car?*" and "*What is the annual energy consumption of an average home?*" - these figures can be misleading.

The Baker Street site was constrained in terms of floor to ceiling heights with clearances only 2.45m in some parts. This helped justify the use of a chilled beam design for HVAC solutions. An analysis of the existing structure found that there was a lot of dead space that could be potentially let to clients. By moving the cores and filling in the light wells, 30% extra lettable floor area was created with minimal additional materials.

In order to "*re-energise*" and "*rebrand*" the building, external windows were replaced, void areas were concealed with glazed structures and façade stone was cleaned. The reception area was opened up by replacing twelve structural posts with a transfer structure. Overall, the Baker Street project was a fine example of judicious use of materials to modernise a building whilst minimising material use in the underlying structure.

## 4.3.8 Cluster 8: Design for deconstruction and re-assembly

### 4.3.8.1 Description of the cluster

Although some structures are inherently designed for multiple deconstruction and disassembly (such as marquees, temporary storage silos, emergency housing and spectator seating) their individual use phase timespans are often very short compared to the typical lifespans expected for residential and office buildings.

In line with the recently published Circular Economy Package and recent versions of green building assessment schemes, it is apparent that there is a growing interest in the potential of more conventional building types to be 'deconstructed' instead of "demolished" in order to maximise the potential for reuse of building components and the separation of wastes for optimum recycling routes.

The studies in this section represent buildings which go beyond simple design for deconstruction and which are actually designed with structures that can potentially be reassembled elsewhere with minimal additional materials and construction work.

Table 4.19 Basic details of selected building projects

Building	Climate zone, Location	Typology	Type	Scale	Stage
Demountable courthouse	Western Europe, Amsterdam (NL)	Office: Low-rise	New build	5400m <sup>2</sup>	In-use, due for deconstruction 2015-16
SEGRO	Western Europe, London (UK)	Office / Warehouse Low rise	New build / rebuild	3320m <sup>2</sup>	New location in use since 2014

### 4.3.8.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

Buildings that are deconstructed and reassembled are the ultimate examples of material efficiency. Material impacts can be spread across each new use of the building/building component. The reuse of entire buildings or building components has triple benefit of reducing site waste generation, reducing demand for raw materials and avoiding associated costs. Buildings designed for deconstruction and reassembly have adaptability at the heart of their design.

Specific actions involved in these projects include:

- Use of deconstruction friendly features such as bolted instead of welded beams, use of precast concrete elements instead of in-situ poured concrete, modular floor coverings and wall cladding;
- Feasibility assessment of deconstructing different building components for deconstruction (i.e. glazing, raised floors, suspended ceilings, services, roof, indoor and outdoor cladding and the structural frame.);
- Adequate handling, correct transport and storage of materials to prevent damage;
- Adequate handling and installation onsite and assessment of total material and cost savings compared to a new build project.

#### 4.3.8.3 How performance improvements were measured

With the SEGRO project, material quantities reused were logged and translated into embodied carbon savings (-56%) and capital cost savings (-25%) compared to what would have been required to build a new Part L UK Building Regulation compliant building of equivalent size.

With the Dutch courthouse, the improvements are not yet evident due to the fact that reports of the deconstruction of the building have not yet been published. Nonetheless, the project is novel because it has been procured according to a so-called Design, Build, Maintain and Remove (DBMR) whereby the construction company is responsible for the future dismantling of the building to make way for a later permanent construction. The principal of the agreement is that the entire building could potentially be reassembled elsewhere.

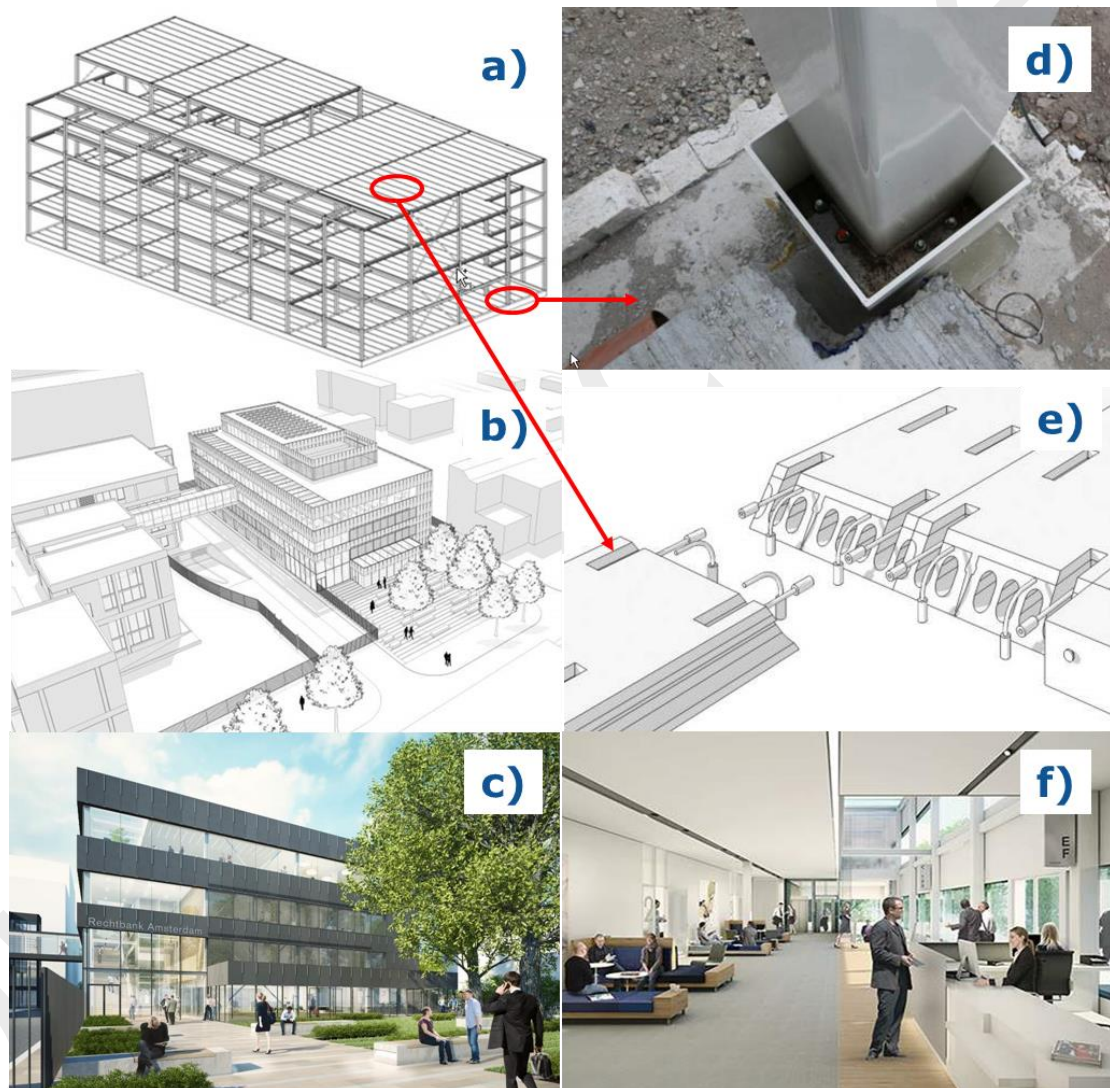


Figure 4.19. The Demountable Courthouse in Amsterdam: a) Frame and floor layout, b) and c) final building external views, d) demountable design feature (anchorbolts), e) demountable flooring and f) final building internal view.

#### **4.3.8.4 Implementation experience of practitioners involved with delivery of the improvements**

##### *Project Specific feedback*

SEGRO is a real estate investment trust with a portfolio of modern warehouses, light industrial buildings, data centres, retail buildings and office buildings. With their office and warehouse building in Leigh Road, Slough, UK, the building had to be removed or demolished due to construction of the Leigh Road bridge. The initial building design was not originally intended to be deconstructed for later reassembly. Despite this fact, a feasibility study revealed that it would be possible to reuse the complete steel frame, the office glazing system, lift, raised floor sections, joinery, block paving, fence and even trees from the existing site. The new site was less than 1km away so transport did not have a major impact.

Compared to a new build scenario, embodied carbon savings of 56% and cost savings of 25% were calculated. Due to the success of the project SEGRO, who invest in modern warehousing, light industrial buildings, data centres, retail and office buildings, have identified design for deconstruction and reassembly as a key indicator for their business model, setting out solid sustainability credentials for their buildings and their ability to maximise asset use in line with changing market demands.

According to SEGRO's estimates, with future buildings that they may invest in, and which have specifically been designed with deconstruction and reassembly features in mind, embodied carbon savings could be increased from the 56% in this study to around 80-90% when comparing deconstruction and reassembly to new build scenarios. They confirmed that most of the capital cost savings were due to the reuse of the structural steel frame and that external works, such as earthworks and utility connections, were excluded from the cost comparison.

##### *Cross-cutting feedback*

The incorporation of design features that enable or enhance the degree to which a building can be deconstructed and potentially reassembled is becoming more commonplace, particularly with the promotion of the Circular Economy Package of the European Commission.

Such features lend themselves best to buildings that typically have short expected lifespans, although they are now being considered in longer term office building projects. The ability to deconstruct and reassemble buildings improves the performance of building assets in multiple different ways. The capital cost invested in building materials can be successfully retained if the building needs to change location for whatever reason. Designs that allow for deconstruction offer a much greater degree of adaptability as well, when commercial demands require minor or major alterations.

## **4.4 Findings from the operational experience of selected assessment and reporting schemes**

### **4.4.1 Assessment and reporting schemes**

In this section, a summary of the main themes and findings to have emerged from a detailed cross-check of relevant criteria from the five analysed certification schemes – BREEAM UK, HQE, DGNB, LEED and VERDE (based on SB Tool) - together with associated interviews are presented.

Reference is also made to the criteria of a number of residential-only schemes – Home Performance Index (Ireland), Home Quality Mark (UK), Klimaaktiv (Austria) and Miljo Byggnad (Sweden).

The main observations are grouped into common themes that emerged from the research.

#### **4.4.1.1 Material efficiency**

In one scheme this had been introduced as a specific criteria area. This was the result of dialogue with professional institutes. The aim has been to encourage a focus of attention in this area. No specific methodology is provided as they wish to see how applicants respond.

#### **4.4.1.2 Construction and demolition waste reporting**

The response to this criteria area has depended on the prevailing culture in each country. In those countries with high awareness of and a culture of construction waste management, the reporting systems tend to be in place and there are tools to help monitor performance. In at least one case, reporting is seen to be of little added value since it is already widely practiced.

Operating such a criteria internationally was considered to require leaving open the choice of measurement units and reference benchmarks, e.g. the average national rates.

#### **4.4.1.3 Addressing future durability, life span and adaptability**

These areas are a relatively new focus of attention and have tended to have a low initial response compared to performance based criteria. However, it was noted that in some countries there are specific legislative requirements that address building lifespan and maintenance.

In the case of Germany, where adaptability has been pioneered as a criteria area by DGNB, it is already considered to be embedded in how designers think, so the potential for adaptable design tends to be limited by the impact that it may have on initial construction costs. There is also considered to be a trade-off between efficient initial use of floor area and leaving reserves for future adaptability.

The state of the art is considered to be a checklist based approach, requiring either a qualitative evaluation of the applicants response or the use of a weighted scoring tool that gives a quantitative outcome. In the case of the former, assessment relies to a great extent on the assessors judgement.

Where the assessment is currently qualitative, there is the intention to move towards a more robust and verifiable criteria. The importance of addressing the potential for changes of use was highlighted in one case, based on feedback from property investors.

Existing legislation may provide a calculation methodology for the lifespan of building structures, or set out specific requirements for maintenance plans to be prepared. A suggestion was made that, in the future, criteria requiring maintenance plans could be checked for implementation after several years of building occupation.

#### **4.4.1.4 Addressing future ease of disassembly**

In some countries, this aspect was considered by applicants to be easy to respond to, but in others, a combination of it there being a low general awareness of waste management issues and this being a very new focus of attention, has limited the response.

Assessment tends to rely to a great extent on the assessors judgement and expertise, with the exception of when a category-based scoring methodology is provided. Training assessors to be competent in this criteria area was a particular challenge.

In the case of one country where this has been pioneered as a criteria area, the approach has been changed. The initial focus on category scores focussing exclusively on design for disassembly, has now been expanded to also include recyclability. This was because the initial focus was too inflexible, and didn't serve to incentivise improvements for some more common types of construction, which simply weren't able to pick up credits as a result.

#### **4.4.1.5 Using LCA to assess significant environmental impacts**

In general the take up of LCA-based criteria applying to a whole building is understood to be low, with the exception of cases where: it is a compulsory criterion (DGNB); the credits available are weighted significantly (DGNB, BREEAM); and/or applicants are supported by a user friendly EPD rating system, such as the Green Guide that supports BREEAM UK.

The time and cost of carrying out an LCA was highlighted as a potential barrier. Because of this moves have been made by some schemes to try and offer simplified approaches. For example, DGNB proposes to introduce a simplified LCA method, with further credits then available to encourage design optimisation and the use of specific data. In France the ELODIE LCA tool has to be purchased, but this may change in the future.

Where carrying out a full LCA for the building is compulsory, as in the case of DGNB Germany, the main focus is on encouraging applicants to carry out an LCA. The approach of DGNB, BREEAM and LEED differ in how they refer to a reference building to be used as a benchmark. BREEAM and LEED leave definition of the reference building open, whereas DGNB defines the reference according to building permitting requirements for energy performance.

In the case of DGNB, a relatively prescriptive set of rules have been developed to guide users and improve comparability. These are aligned with EN 15978, but the standard is considered to be relatively 'open' and so simply referring to the standard was not enough. Some life cycle stages are omitted (A4/5, C1/2) because the effort require to obtain data is not warranted because of lower life cycle significance of these stages.

BREEAM currently screens and appraises the available methodologies and software tools for suitability, with a comparative scoring based on their comprehensiveness.

How to handle data gaps is a source of questions from assessors. In the case of DGNB and HQE, national databases are available, but expert judgement of how to work with data may be needed. There are still gaps in available data for certain building product types – as identified by the HQE Performance project. In France a generic database is also being created to support HQE and the new voluntary embodied carbon label (BBCA).

A new generic, indicator-based LCIA database (ESUCO) linked to the German national database is being developed for DGNB. The Spanish Green Building

Council may also seek to work with partners on a generic database and software tools to support applicants.

Draft document

## 4.5 Identification and screening of potential performance indicators

### 4.5.1 Long list of macro-objective 2 direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope			Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage	Building aspects			
<b>2.1 Structural design optimisation</b>							
<b>Material mass per unit</b>	Kg/dwelling unit m <sup>2</sup> /GIFA or total floor space	A4-5: Construction	Strategic definition and brief Concept design Developed and technical design	Substructure Superstructure External envelope	Schedule Bill of Quantities	-	FS CC
<b>Structural material mass</b>	Kg/unit load bearing capacity and component length	A4-5: Construction	Concept design Developed and technical design	Substructure Superstructure	Eurocodes Bill of Quantities	-	CC
	m <sup>3</sup> structure/m <sup>2</sup> GIFA	A4-5: Construction					CC
	Utilisation ratio	A4-5: Construction					CC
<b>2.2 Design for flexibility and adaptability</b>							
<b>Service lifespan</b>	Estimated in years	B1-7: Use	Strategic definition and brief Concept design Developed and technical design	Building, elements or components	-	-	See 6



<b>Adaptability score</b>	Weighted sum of 7-15 aspects	B1-7: Use - Repair - Replacement - Refurbishment	Concept design Developed and technical design	Building arrangement, floor layouts, servicing strategies	<i>With reference to assessment scheme methodologies</i>	-	AR CC
<b>2.4 Construction and demolition waste minimisation</b>							
<b>Reuse or renovation of buildings/elements</b>	% (mass)	B5: Refurbishment C1-4: End of Life	Concept design Developed and technical design	Building, elements or components	-	-	AR CC
<b>% of structure reused</b>	% (volume)	B5: Refurbishment C1-4: End of Life	Construction Refurbishment	Superstructure Substructure	-	-	FS
<b>% of façade reused</b>	% (surface) % (mass)	B5: Refurbishment C1-4: End of Life		Façade and envelope elements	-	-	FS
<b>Waste arising during construction and/or demolition</b>	m <sup>3</sup> or m <sup>3</sup> normalized per 100 m <sup>2</sup> floor area or m <sup>3</sup> normalized per project cost	A4-5: Construction	Developed and technical design	Excluding waste from earthworks/excavations and backfilling	Protocols developed by sectoral organisations, industry and Member States	-	CC AR
		C1-C4: End of Life	Construction			-	CC AR
	tons or tons normalized per 100 m <sup>2</sup> floor area or tons normalized per project cost	A4-5: Construction				-	CC AR
		C1-C4: End of Life				-	CC AR

<b>Material recovery ratio / Proportion of waste diverted from landfill</b>	% diversion rate	C1-C4: End of Life	Technical design Demolition	Whole building and infrastructure (excluding excavated soil). Recovery= reuse, recycling, energy recovery.	<u>Data:</u> Bill of quantities or demolition inventory (design); processing certificates or invoices (demolition)	-	FS AR
<b>2.3 Design for deconstruction and disassembly</b>							
<b>Ease and scope of disassembly</b>	Category score	C1-4: End of Life	Concept design Developed and technical design Construction	Building, elements or components	<i>With reference to assessment scheme methodologies</i>		AR CC

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

#### 4.5.2 Long list of macro-objective 2 supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>2.4 Construction and demolition waste minimisation</b>							
<b>Amount of contaminants in recovered fractions</b>	<b>% (mass)</b>	C1-4: End of Life	Demolition	Processed waste streams (e.g. after sorting)	Depending on waste stream. For recycled aggregates EN 933-11 is used in regional and European standards	Depending on waste stream	FS

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 5. Macro-objective 3: Efficient use of water resources

### 5.1 Defining the macro-objective's scope and focus

#### 5.1.1 Policy and technical background to selection of the macro-objective

##### 5.1.1.1 The Blueprint for water

In the first Working Paper, the Communication COM (2012)673<sup>135</sup> was identified as an important policy reference. The *Blueprint to safeguard Europe's water resources* aims to achieve better implementation of current water legislation (including the Water Framework Directive<sup>136</sup>), the integration of water policy objectives into other policies, and to address gaps in policy on water quantity and efficiency.

The scope to improve water efficiency of industry and buildings was emphasised as being important in order to counter trends towards greater water scarcity and stress. Water efficiency targets are proposed to be established at river basin level, taking into account levels of water stress. Special objectives identified include increased metering take-up, efficiency in buildings and maximisation of water re-use.

##### 5.1.1.2 Mandatory and voluntary product policy

The following policies and initiatives are of direct relevance to the water consumption of buildings:

- (i) the inclusion of water-related products in the Eco-design working plan and
- (ii) the development of voluntary EU Ecolabel and Green Public Procurement (GPP) criteria for water-related products.

Eco-design criteria, in accordance with Directive 2009/125/EC, set out minimum efficiency requirements for energy related products in order for them to be placed on the EU market. Criteria for household washing machines and household dishwashers are set out in Regulations 1015/2010 and 1016/2010 respectively. Although taps and showers could be argued to be energy related products where hot water is involved, to date no eco-design criteria for these products have been published.

EU Ecolabel criteria, in accordance with Regulation (EC) No 66/2010, are voluntary minimum criteria which a product must comply with in order to be able to carry the EU Ecolabel. Criteria have been published for Flushing Toilets and Urinals (Decision 2013/641/EU) and Sanitary Tapware (Decision 2013/250/EU).

EU Green Public Procurement (GPP) criteria are voluntary criteria that are set at the EU level and which may be fully or partially implemented as environmental criteria into invitations to tender set by public authorities across Europe. At the present moment, EU GPP criteria exist for sanitary tapware and for toilets and urinals.

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<sup>135</sup> COM(2012)673 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *A Blueprint to Safeguard Europe's Water Resources*

<sup>136</sup> Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

### 5.1.2 The intended scope and focus

The macro-objective is to achieve more efficient use of water resources during the use phase of the building life-cycle, particularly in the case of buildings located in areas of identified long-term or projected water stress.

In practical terms, the macro-objective will focus on improving water efficiency in areas of water stress, but will draw upon wider experience from other areas too. This shall include reference to criteria in building assessment schemes and efficiency measures that are driven by a combination of building regulations and cost savings in areas with more abundant water resources e.g. UK, Belgium.

## 5.2 Cross-cutting investigation of the macro-objective's implementation

### 5.2.1 National and regional initiatives

The Blueprint for water emphasised that reductions in water consumption are more important in some regions than others. This can be related to two principal factors:

- The average water consumption levels in the region (i.e. the potential for improvement and need for reduction would be highest in regions with high average consumption rates).
- The degree of water stress in a particular country, region or river basin (i.e. reduction will be most important in areas of high water stress).

Consequently, when considering potential indicators for water consumption in buildings, it may be helpful to make reference to the regional context.

#### 5.2.1.1 Regional variations in water consumption

It is difficult to compare the total water consumption patterns of countries due to different degrees of industrialisation, agriculture and other non-domestic uses of water. Nonetheless, a reasonable comparison between countries can be made when focussing on domestic water consumption, which are compared in Figure 5.1 below for EU-28 countries.

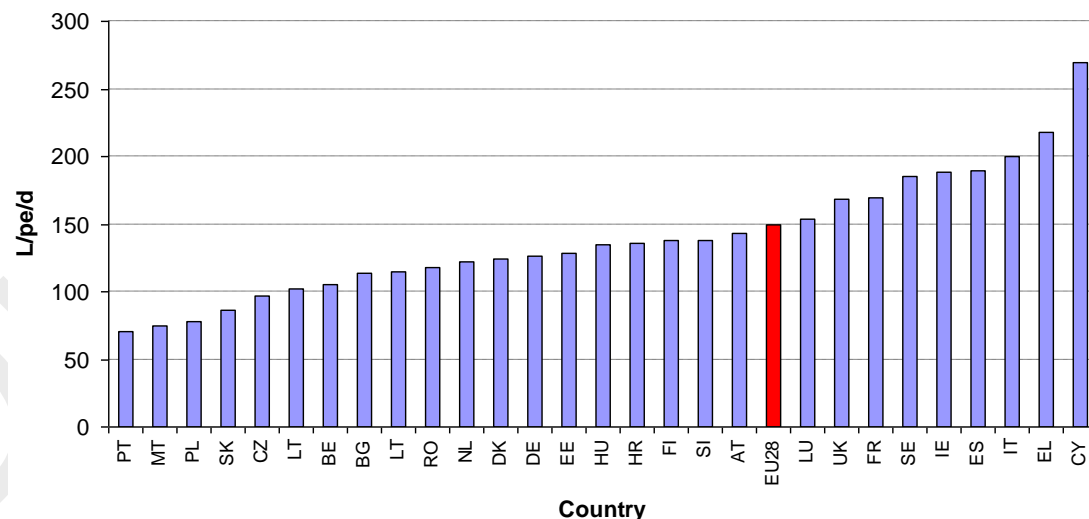


Figure 5.1 Per capita domestic water consumption in different EU28 countries (Source: EUREAU Statistics Overview on Water and Wastewater in Europe 2008).

Higher standards of living are changing water demand patterns. This is reflected mainly in increased domestic water use, especially for personal hygiene. Domestic water use varies among countries, regions and persons, depending on factors

which include: product technology mix, use practices, cultural behaviour and the policy instruments deployed in a certain territory. From Figure 5.2 it is clear that there is a wide range of specific domestic water consumption in different countries.

A further analysis of the domestic water consumption data to estimate how domestic water consumption was split between different uses (i.e. toilets, showers and taps etc.) was carried out by the JRC as part of an Ecodesign Preparatory study.

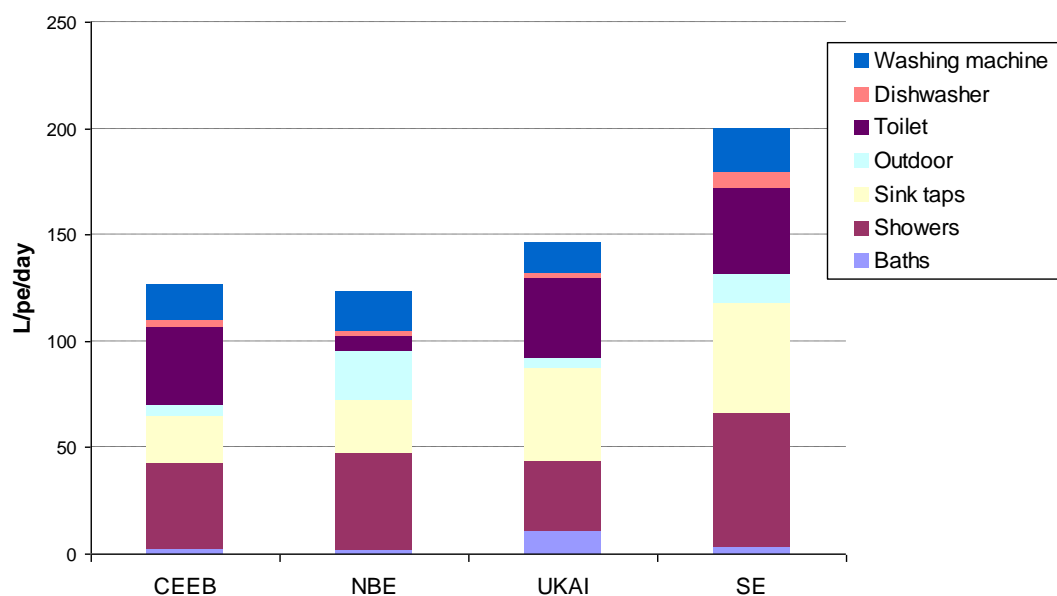


Figure 5.2 Per capita domestic water consumption in different European regions (CEEB – Central and Eastern Europe and Balkans; NBE – Nordic and Baltic Europe; UKAI – UK and Ireland and SE – Southern Europe).

The findings from Figure 5.2 show a clear increase in overall domestic water consumption in southern European countries, as well as the significantly higher use of water for baths instead of showers in the UK and Ireland and the very low per capita water consumption for toilet use in Nordic and Baltic countries.

From the findings summarised above, there is certainly a case to promote water use indicators in buildings in southern European countries, especially the highest consuming countries such as Cyprus, Greece, Italy and Spain.

### 5.2.1.2 Regional contextualisation based on water scarcity

Water differs from other resources due to the unique characteristics as it moves through the meteorological, hydrological and hydrogeological cycles. Because of this, the availability of water varies in time and space, and also within countries.

Even when water is abundant on a national scale, local areas may experience conditions of water shortage or over-exploitation of water during different time periods or seasons. This is typical for river basins and touristic areas in the Mediterranean regions, but also for urban centres, for small islands and for some northern regions<sup>137</sup>. The phenomenon can be worsened in case of drought conditions, which have been recorded all across Europe, as shown below.

<sup>137</sup> European Environment Agency, *Water resources across Europe – confronting water scarcity and drought*, EEA Report No2/2009

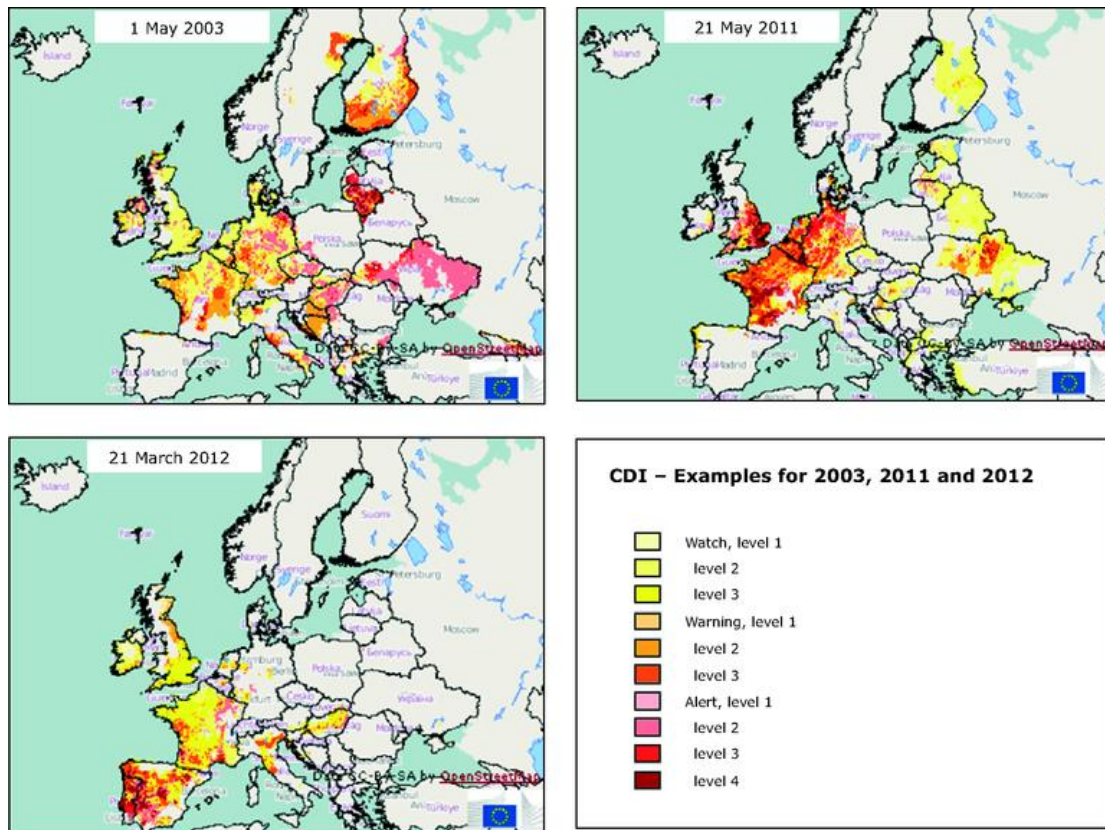


Figure 5.3 Drought conditions in Europe over time (CDI=Combined Drought Index) Source: European Environment Agency (2012)

A measure of the water depletion stress is represented by the Water Exploitation Index (WEI), which is expressed as the percentage of fresh water available in a certain area that is withdrawn to fulfil the water needs of that area. The WEI forms part of the EU's dashboard of resource efficiency indicators.

According to the European Environment Agency, three different levels of water scarcity can be arbitrarily defined:

- WEI < 20%: a non-water stressed region
- WEI 20-40%: a water stressed region
- WEI >40%: a severely water stressed region.

At the national level, the countries with highest WEI factors are: Cyprus (ca.65%), Belgium (ca.32%), Spain (ca. 30%) and Italy (ca.25%). With the notable exception of Belgium, each of these countries also have the highest per capita domestic water consumption rates – further highlighting the importance of water efficiency measures in these countries.

Within many countries there may be significant local or regional differences in terms of climate and therefore it is possible that national level WEI factors may under- or over-estimate the degree of importance of water efficiency measures. For example, in 2009, a national WEI of 34% for Spain masked severely water stressed river basins in Andalusia and Segura, which had WEIs of 164% and 127% (see Figure 5.4).

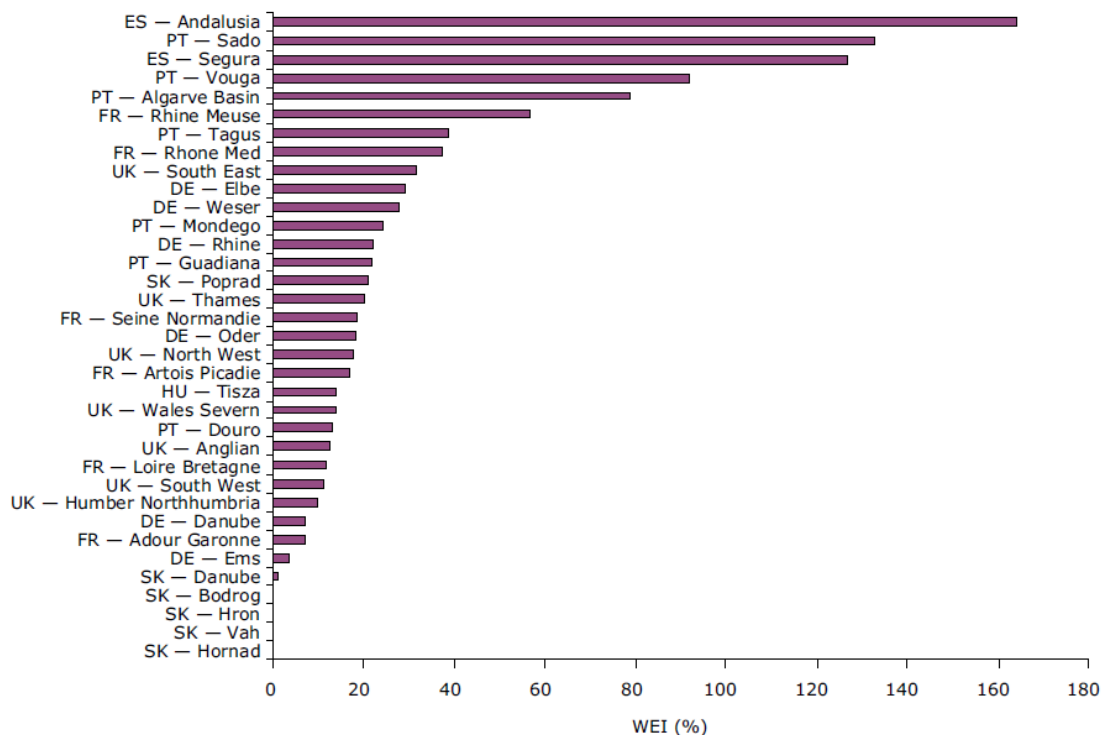


Figure 5.4 WEIs for different river basins in selected member states

The additional detail at river basin level can therefore provide a much more relevant scenario. However, the WEI is calculated using annual data and it has been commented that even river basin level data will miss certain potentially important factors related to seasonality and types of consumption. For example, in river basins with a strong tourism or agricultural sector, water demand will be highest in summer, precisely at the point when rainfall is lowest.

Furthermore, the WEI does not distinguish between water that is abstracted for the cooling of power plants (where the majority of abstracted water is returned to source) and agriculture (where most water is evapotranspired or remains in harvested crops).

Nonetheless the WEI is considered by the EEA to be a useful starting point for identifying water scarcity, and there are plans for further development for its use as an indicator of water stress.

### 5.2.1.3 Regulation and labelling for sanitary fittings and appliances

In addition to the EU Ecolabel, a number of voluntary labelling schemes exist for sanitary fittings on the European market, which include:

- The European Water Label is an industry-backed voluntary labelling system for: baths, WC suites, cisterns, basin taps, shower controls, shower handsets, greywater recycling units, kitchen taps, urinal controllers, electric showers, replacement WC flushing devices, supply line flow controllers and independent WC pans. Labels are split into 1 of 5 different coloured performance bands that are linked to water consumption rate ranges of the product.
- ANQIP (Associacao Nacional para a Qualidade nas Instalacoes Prediais)) which provides a labelling system for flushing cisterns, showers and showerheads, flow reducers and valves and flowmeters in Portugal with labels ranging from E to A++ as a function of water efficiency or the product.

- The Swedish Energy Efficiency label, which provides a labelling system for hand basin and kitchen mixer taps and for thermostatic mixing taps with showerheads. Products are rated from A-G based on their energy performance and it should be noted that while the calculation method to determine energy performance does account for water efficiency, low flow products are not automatically calculated to be better than higher flow products.
- The Water Efficiency Label (WELL) is a product classification system of the European sanitary valve industry that can be applied to shower valves, showerheads, shower hoses, urinal flush systems and WC flush systems. The classification system differentiates between domestic and non-domestic sectors, to which additional hygiene requirements also apply.

These schemes allow verified performance data to be provided for the calculation of water consumption.

## **5.2.2 Building permitting and planning requirements**

Regulation is the most direct measure to take when attempting to reduce water consumption and has tended to focus on minimum requirements for fittings in sanitary devices. This section provides a brief review of some notable regulatory approaches used in different parts of Europe.

### **5.2.2.1 Building Regulations Part G, England (UK)**

Part G of the 2010 Building Regulations for England set out minimum requirements for sanitation, hot water safety and water efficiency for all new buildings in England<sup>138</sup>. Specifically Part G2 relates to water efficiency and sets out a baseline benchmark, specific water consumption of 125 L/person/day, based on user behaviour in domestic buildings and an optional higher ambition level of 110 L/person/day in local areas where it can be justified.

In order to avoid being overly restrictive to user choices for certain "luxury" products, a flexible approach is laid out with two possible routes to compliance:

- i. By means of a fittings approach for taps in kitchen sinks, bathroom sinks, washing machine, dishwasher, showers, toilet and bathtub where each must meet a minimum performance level.
- ii. By means of a calculator where some fittings may have higher water consumption rates than specified in the fittings approach so long as they are adequately compensated for by other fittings.

Feedback during a consultation exercise was generally supportive of the Building Regulations as the appropriate means to deliver on government targets to improve water efficiency in new homes. However, anecdotal feedback from certain post-implementation experience has revealed that there is some degree of practice where efficient fittings are put in to demonstrate compliance with the Building Regulations then removed when the final occupant moves in (either due to poor satisfaction with shower speeds or choices to redecorate to their taste).

Compliance with the dishwasher and washing machine requirements is complicated when occupants bring their own older appliances with them for which water efficiency information may not be available. Other wider criticisms targeted potential concerns with poorer flushing of drains caused by lower wastewater flow rates and potentially simpler measures to reduce water consumption via the use of tiered tariffs or infrastructure improvements to reduce leakage in the mains distribution system.

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<sup>138</sup> HM Government, *The Building Regulations 2010 – Part G: Sanitation, hot water safety and water efficiency*, 2015 edition, UK.



A comparison of the requirements laid down in the UK with the other example analysed in Madrid (Spain) is presented in Table 5.1 (See the next Section).

### 5.2.2.2 Water ordinance, Madrid (Spain)

The city of Madrid has a hot and dry climate yet must consume water to meet the needs of around 5 million citizens. In the absence of national planning Regulations, Madrid's "Ordenanza de Gestion y Uso Eficiente del Agua" (2006) is the most significant planning Regulation relating to water consumption in buildings.

The regulation covers potable water use in buildings and in public areas and gardens, metering, major consumers and the use of recovered water, stormwater and greywater. All new buildings since 2006 must be installed with water meters and all existing buildings had to have meters installed by 2009.

Requirements are set out for: fittings used in bathrooms and kitchens, maximum pipe distances from boiler to hot water tap (15m), irrigation systems, fountains, swimming pools and greywater reuse. Major consumers of water (>10,000m<sup>3</sup>/year) are required to submit a Sustainable Management Plan for efficient water use for a four year period which must be approved by the municipal authority every four years.

The Madrid regulation does not link directly to a calculation scheme and does not address the issues of kitchen appliance water consumption although it does set ambition levels that are comparable to the baseline UK requirement for other fittings. The minimum requirements for fittings in buildings depend on whether the building is for public or private use. The requirements are summarised in Table 5.1 and are also compared to those of Part G of the English Building Regulations.

Feedback on the impacts of the Madrid regulation confirmed significant behavioural change and improvements in the water consumption of major consumers although data for normal households has not been analysed so far<sup>139</sup>.

Table 5.1 Comparison of requirements for water efficient fittings (UK and Madrid)

Fitting	Use type	Madrid	UK	
			125L/pe/d goal	110L/pe/d goal
Taps	All/private use	≤ 6 L/min at 2.5kg/m <sup>2</sup> pressure	≤ 6 L/min (basins) or ≤ 8 L/min (sinks)	≤ 6 L/min (basins) or ≤ 8 L/min (sinks)
	Public facilities	≤ 1 L/use by use of timers		
Shower	All/private use	≤ 10 L/min at 2.5kg/m <sup>2</sup> pressure	≤ 10 L/min	≤ 8 L/min
	Public facilities	Thermostatic valves should be linked to a timer		
Toilet	All/private use	≤ 6 L/flush plus a dual flush button or interrupter	≤ 6L / 4L dual flush or ≤ 4.5L single flush	≤ 4 L / 2.6L dual flush
	Public facilities	Urinal flush should be automatically triggered by proximity sensors and counters.		
Bath	Private use	-	185 L	170 L
Dishwasher	Private use	-	1.25 L/place setting	1.25 L/place setting
Washing machine	Private use	-	8.17 L/kg	8.17 L/kg

Source: Ayuntamiento de Madrid (2012), UK Government (2015)

<sup>139</sup> Personal communication with Soledad Checa Sanchez – Ayuntamiento de Madrid

## 5.3 Findings from investigation of the selected field study clusters

The macro-objective B3 field studies consist of four clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- ALTO offices – new-build and residential (France and Luxembourg): Operational water use;
- ALTO residential – MacDonal masterplan (France): Operational water use;

For each cluster, the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

### 5.3.1 Cluster 1: ALTO offices – new-build and renovation

#### 5.3.1.1 Background and context to selection of the cluster

*An overview of this ALTO building cluster is provided in Section 2.4.*

#### 5.3.1.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

Each building was certified to HQE, BREEAM, LEED and DGNB. The performance targeted on each building project differed for each assessment scheme (HQE, BREEAM, LEED, DGNB) and the year of registration.

The following areas of focus for improvement were identified on the projects. They are related in each case to the distinct requirements of each assessment scheme.

##### 5.3.1.2.1 Reduction of water consumption in use stage

During construction, the performance of sanitary appliances to be fitted had to be verified based on manufacturer's data sheets provided by the contractor. Calculations were updated in the case of variation. The process of verification was with respect to the multiple certification criteria, which in summary were as follows:

- HQE: The consumption (L/person/day) of the assessed building is compared to a baseline performance and is expressed as a % of compliance with the certification requirements.
- BREEAM: The consumption ( $\text{m}^3/\text{person}/\text{day}$ ) of the assessed building is compared to a baseline performance. BREEAM credits are awarded if consumption value is less than  $5,5\text{m}^3$  per person per year. Maximum credits can be achieved when consumption is lower than  $1,5\text{m}^3/\text{person}/\text{year}$
- LEED: The consumption (L/person/day) of the assessed building is compared to a baseline performance and is expressed in a % of reduction.
- DGNB: Limit values are calculated for each project in ( $\text{m}^3/\text{year}$ ). The target value can be reached with savings from innovative water-saving installations (for example, waterless urinals), intelligent irrigation strategies, use of grey water and/or use of rainwater. The "water use value" is created by adding the calculated potable water demand and the volume of waste water. This value is a clear representation of the water management in the building.

Regarding the methodologies used to verify the building water use, each certification scheme uses its own calculation tool. Calculations are based on technical data and occupation assumptions compared to a reference value and

are stipulated by each certification scheme. In general, the calculation methods fall into two broad categories:

1. Determine consumption based on reference data for building occupant consumption patterns
2. Determine consumption based on reference data or manufacturers data for sanitary fittings.

Outdoor water usage tends to be handled as a separate calculation. In some cases, certification schemes distinguish between uses where potable water is required and those where other lower grades of water may be used. A link is then made to how these lower quality grade uses are serviced e.g. using rain water, grey water

#### **5.3.1.2.2 Strategies to reduce the water demand (rainwater harvesting, grey water harvesting, etc.)**

Grey water recycling or rain water reuse are not necessary to respect HQE water criteria but to get the maximum environmental value under DGNB, BREEAM and LEED, projects have to specify that these systems are applied. Furthermore, the design teams own calculations may additionally be required in order to provide the necessary input to the water calculation tools of each assessment schemes. In some cases the calculation methodology is detailed in the criterion guidance – for example in the case of the DGNB Scheme.

Rainwater harvesting : Additional local regulation is considered in case of tour La Marseillaise (imposition on peak rate of run off and predicted volume of rainwater discharge linked), Zenora (a special local planning district which requires reuse of rainwater) and CBK II (reuse of rainwater is common in Luxembourg).

Greywater reuse is considered in the BREEAM 2009 calculation tool. HQE does not include for the reuse of grey water at the present time in its calculation of water consumption. DGNB and LEED consider the reuse of grey water in their calculations (for instance, grey water that is used instead of potable water is subtracted from the water demand).

#### **5.3.1.2.3 Monitor water consumption by installing water meters and a Building Management System (BMS)**

All certification schemes require sub-meters and this is also now required by French regulation on new projects. BMS is not mandatory but this is often linked to the energy performance required by regulation. Projects certified under HQE often provide a BMS to the tenants.

#### **5.3.1.3 How performance improvements were measured**

*Potential indicators identified:*

- Net water consumption reduction against a baseline reference value (considering flow rate of sanitary appliances, proportion of grey water re-used and rain water reused).
- Water consumption during construction.

*Supporting indicators:*

- flow rate of sanitary appliances (l/flush for cisterns, urinals; l/minute for washbasins, showers).
- grey water re-used .
- rain water re-used.

- Installation of water metering, including sub-metering for high water using functions.

Different units of measurement and calculation tools are used depending on the certification scheme: % reduction compared to reference value; m<sup>3</sup>/year (per building); m<sup>3</sup>/person.year (per occupant).

#### **5.3.1.4 Implementation experience of practitioners involved with delivery of the improvements**

In Luxembourg, reuse of rainwater is common practice and makes an important contribution to the goal of net water consumption reduction. The client was already aware of the cost and accessibility of this measure as well as potential impact.

It was found that the design team and contractors are not always aware of how implementing water efficiency measures may affect their normal way of working. This was illustrated in the case of CBK II, where achieving the goals linked to the triple certification (DGNB, BREEAM, HQE) during design and construction proved to be difficult to manage for the environmental consultant.

Even though the DGNB certification scheme is not common in Luxembourg or France, the calculation tool is relatively straight-forward to use and is well-explained in the certification scheme manual. A particular advantage of the DGNB calculator was its transparency, where all of the calculations and assumptions behind them were described. By integrating rainwater and greywater reuse into the equation, it is easier to compare water use values from different projects. Other calculators, such the BREEAM 2009 one, use a "black box" approach, which are not so easy to understand how values are calculated.

##### *LA MARSEILLAISE, Marseille*

The LEED V3 scheme is linked to American standards, which are more ambitious than the European schemes (i.e. HQE, DGNB, BREEAM). For example, 9.5L/min is required for showers compared to 14-15L/min for the European schemes.

Attempting to fulfill all the LEED v3 requirements has contributed to delays in the project, which is still at the design stage. Penalties have been included in the agreement with contractors should the final building not meet specified requirements for certification. Where any shortcomings can be linked to improper design, these penalties can be applied to the design team.

##### *ZENORA, Paris*

Reuse of rainwater for irrigation and sanitary use and grey water recycling had been withdrawn to save on costs and design complexity but then reintegrated to the project in order to obtain more credits.

The DGNB calculation tool and accompanying guidelines were straight-forward and easy to work with. Minimal scope is left for interpretation and the use of different assumptions (which is often not the case for the calculation tools of the other building certification schemes). This increases the comparability of the water use of buildings between different projects. The standard ambition levels of the certification criteria were not difficult to achieve.

## 5.3.2 Cluster 2: ALTO residential masterplan

### 5.3.2.1 Background and context to selection of the cluster

An overview of this ALTO building cluster is provided in Section 2.4.

### 5.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

ALTO Ingénierie was the environmental consultant for all 15 of the building units. The buildings had to achieve the following certifications: "Habitat & Environment (H&E)"<sup>140</sup> and "Bâtiment Basse Energie (BBC)"<sup>141</sup>. The following areas of focus for improvement were identified:

#### 5.3.2.2.1 To reduce the consumption of potable water for sanitary use

The residential certification lead by CERQUAL<sup>142</sup> does not specify a limitation of global water consumption per flat/home per day or year or person. As a result only few requirements are linked to the certification schemes:

- Toilet flush WC 3/6 litres per flush
- Maximum distance of 10m between production and point of use max
- Pressure of 3 bars (NF EN 1567)
- Sanitary appliances classified ECAU / E1C2<sup>143</sup>
- Showers and Bathtubs with Thermostatic mixing valve
- Individual meters in each apartment

The certification scheme lays stress on the quality framed by French rate ECAU<sup>143</sup> "E" linked to the water flow rate (while C, A and U relate to ergonomic, acoustic and durability requirements respectively). Parameter "E" is split into the following performance levels:

- E0: (9 l/min ≤ q < 12 l/min)
- E1: (12 l/min ≤ q < 16 l/min)
- E2: (16 l/min ≤ q < 20 l/min)
- E3: (20 l/min ≤ q < 25 l/min) – Minimum for bath
- E4: (25 l/min ≤ q)

To respect the requirement C2, sanitary equipment must provide an "economy mode" push-button which limits the water flowrate to between 6,6 l/min and 0,14 l/min.

### 5.3.2.3 How performance improvements were measured

*Potential indicators identified:*

- flow rates per sanitary appliance [l/min]
- classification of sanitary appliances [rating e.g. ECAU<sup>143</sup> in France]
- Individual meters in individual dwelling units

<sup>140</sup> Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

<sup>141</sup> BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

<sup>142</sup> CERQUAL is a French certification body for low energy building certifications in France

<sup>143</sup> CSTB (2016) *Le classement ECAU* [online], available at <http://evaluation.cstb.fr/classement/ecau/> [20/5/2016]

#### **5.3.2.4 Implementation experience of practitioners involved with delivery of the improvements**

Achieving H&E (HQE) certification was pushed for from several different angles: client expectation, the aims of the environmental management system of the developer and most importantly, a mandatory requirement for certification set out in the masterplan.

Overall, meeting the water consumption requirements for certification was not a significant challenge for the design team or contractors. It was possible to directly use data from suppliers in calculations and post-construction performance was checked to ensure it fulfilled design conditions. The design team felt an actual water consumption target would have been more interesting to work towards but also more challenging.

## 5.4 Findings from the operational experience of selected assessment and reporting schemes

### 5.4.1 Assessment and reporting schemes

The current versions of all five of the multi-criteria schemes reviewed (BREEAM UK, HQE, DGNB, LEED and VERDE) have criteria that relate to water use in buildings. All schemes consider the potential of greywater and harvested rainwater to reduce the consumption of potable water.

In terms of targeting areas of water consumption, all schemes focus on indoor water use via sanitary fittings (taps, showers and toilets) while the level of focus on cleaning tasks or the watering of vegetated outdoor areas varies significantly between different schemes.

#### 5.2.1.1 Indoor water consumption – baseline efficiencies of sanitary equipment

The general approach to indoor water use is relatively standardised and in many cases is supported by existing legislation and standards. For example, for residential buildings, BREEAM water calculator is closely linked with Part G of the Building Regulations for England. The VERDE approach is based on input from expert advisory committee and is based on national statistics for household consumption.

All the schemes examined start by establishing a baseline performance level for different sanitary fittings against which improvement can be determined. The baseline values also differ between schemes and are compared in table 5.2.

Table 5.2 Comparison of different sanitary fitting baseline performances.

Scheme	Bathroom taps	Toilet (short flush)	Toilet	Urinal	Shower	Kitchen taps
BREEAM (UK, New construction, non-domestic buildings, 2014)	12 l/min	n/a	6 l/flush	7.5-10 l/hour	14 l/min	12 l/min
VERDE (Residential and offices, v.1c, 2015)	12 l/min	n/a	10 l/flush	n/a	15 l/min	12 l/min
HQE (Non-Residential under construction, Oct. 2014)*	10 l/min	n/a	6 l/flush	3l/flush	12 l/min	10 l/min
DGNB (Core 14 International scheme for new offices)	9 l/min	4.5 l	9 l/flush	3 l/flush	15 l/min	15 l/min
LEED (v4 BDC New construction, 2015)	1.9 l/min (public) 8.3 l/min (private)**	n/a	6 l/flush	3.8 l/flush	9.5 l/min ***	8.3 l/min

\*examples of good equipment \*\* At 415kPa \*\*\* at 550kPa \*\*\*\*at 3 bar or 0.1bar

When calculating the actual indoor water usage, the different schemes have different scopes and levels of complexity. In all cases, the most basic level is to specify water efficient fittings. More complex approaches attempt to match fitting water consumption rates to assumed usage factors (as described in Section . The usage factors are relatively well understood in residential buildings but less so in different types of office building where factors such as use intensity, staff showers and canteens can be irrelevant or highly influential.

The LEED approach sets minimum requirements for fittings and simply sets out minimum requirements for fittings and appliances in commercial buildings but

links to an indoor water use calculator for fittings and appliances in residential buildings.

The BREEAM approach encourages the use of its water use calculator for both residential and office buildings, which have different usage coefficients for offices depending on whether canteen and/or gym/leisure facilities are included in the building. However, a simplified alternative method solely based on the use of fittings is also permitted. Feedback revealed that house builders tend to favour the fittings based approach although this too has been criticised as being overly prescriptive. In the UK, all applicants are already familiar with the fittings and calculator approaches because of its close relationship with the national Building Regulations (Part G2) for England. However, this is not the case in projects under the international scheme.

The HQE scheme provides a calculator which effectively distinguishes between home and office use by letting users of the calculator enter their own usage factors and distinguish between permanent occupants and visitors. However, no accounting is made for water use by kitchen appliances. Whatever the building use scenario chosen, two values should be calculated for that scenario: (i) baseline water consumption using baseline fittings and (ii) reduced water consumption by the use of more efficient fittings. These two values are then used to generate a % improvement.

The DGNB scheme for offices directly states a calculation for water consumption based on number of employees, workdays per year, hard floor area, window area and, where rainwater is harvested, on rainfall and roof area data. Usage assumptions are built into the each of these factors.

### 5.2.1.2 Indoor water consumption – usage of sanitary equipment

Most schemes attempt to translate fitting performance into actual water consumption improvements by assuming certain use factors, which differ between schemes and will differ depending on the type of building (i.e. residential or office). A comparison of the different usage factors for different assessment schemes for residential and office buildings is given in table 5.3 below. Usage is measured in use per person per day (use/p/d).

Table 5.3. Assumed usage factors in different assessment scheme calculation methods.

Sanitary fitting	Office buildings				Residential buildings		
	DGNB	HQE	VERDE	BREEAM	VERDE	BREEAM*	LEED
Toilet (short flush)	2 use/p/d (women)	2 use/p/d (women)	2 use/p/d (women)	3 use/p/d (women)	4 use/p/d	2.96 use/p/d	5.05 use/p/d
Toilet (full flush)	1 use/p/d	1 use/p/d (men)	1 use/p/d	1 use/p/d	1 use/p/d	1.46 use/p/d	
Urinal	2 use/p/d (men)	2 use/p/d (men)	2 use/p/d (men)	3 use/p/d (men)	n/a	n/a	n/a
Shower	30 s/p/d (10% of staff taking a 5 minute shower)	Flexible. Default value of 4.2 s/p/d (1% of staff taking a 7 minute shower)	30 s/p/d (10% of staff taking a 5 minute shower)	52 s/p/d (15.4% of staff taking a 5.6 minute shower)	300 s/p/d (100% of people taking a 5 minute shower)	336 s/p/d (100% of people taking a 5.6 minute shower)	369 s/p/d (100% of people taking a 6.15 minute shower)



Bathroom sink taps	45 s/p/d	15 s/p/d (men) 45 s/p/d (women)	45 s/p/d	60 s/p/d	75 s/p/d	94.8 s/p/d + 1.58L	300 s/p/d
Kitchen sink taps	20 s/p/d	Flexible. Default value of 30 s/p/d	n/a	40 s/p/d	240 s/p/d	26.4 s/p/d + 10.36L	
Dishwasher	n/a	n/a	n/a	n/a	0.4 use/p/d	Default value 4.5 L/p/d. **	0.1 use/p/d
Washing machine	n/a	n/a	n/a	n/a	0.3 use/p/d	Default value of 17.16 L/p/d.	0.37 use/p/d

Notes:

\* Due to no current methodology for BREEAM International, the usage factors from the UK Building Regulations are included here.

\*\* Rises/lowers if consumption is more/less than 1.25L/place setting.

\*\*\* Rises/lowers if washing machine consumes more/less than 8.17 L/kg dry load.

Comparing the usage factors in the table above it is clear that the UK Building Regulation method (listed above for residential buildings in line with that of BREEAM) is significantly different in how it works compared to the other assessment schemes. Nonetheless, all the calculations link back to average flowrates of taps and showers and the average flush volumes of toilets.

The main sources of variation appear to be in the assumptions used for how many employees would use a shower at work and the usage of taps in residential properties. In order to quantitatively demonstrate how the different calculation methods could affect the result, the hypothetical scenarios described in Table 5.4 have been calculated using each methodology. The results are then presented in Figure 5.5.

*Table 5.4. Hypothetical scenarios for office and residential buildings used to compare results derived from water calculation methods.*

Sanitary fitting	Office scenario	Residential scenario
Toilets	Dual flush 6l/3l and urinals that use 2l/flush. 50/50 male/female ratio.	Dual flush 6l/3l
Shower	12l/minute flowrate	12l/minute flowrate
Bathroom taps	10l/minute flowrate	10l/minute flowrate
Kitchen taps	10l/minute flowrate	10l/minute flowrate
Dishwasher	n/a	Consumption is 0.84 l/place setting or 17l per cycle.
Washing machine	n/a	Consumption is 17l/kg dry load or 80 l per cycle.

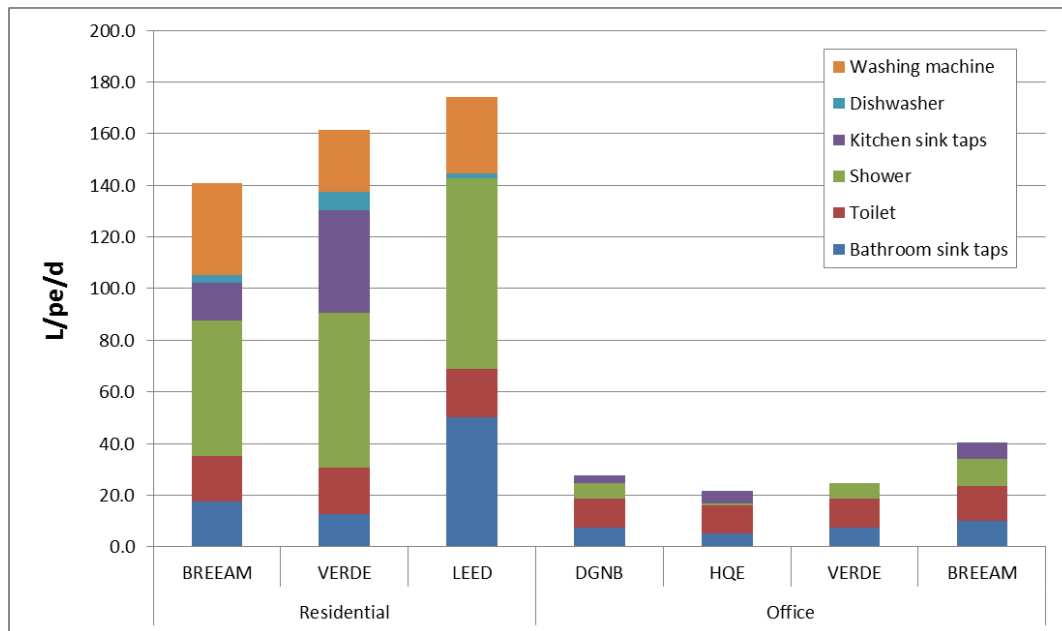


Figure 5.5. Effect of different usage factors on estimated per capita water consumption for different building assessment schemes in residential buildings (left) and office buildings (right).

From the graph above, it is clear that residential water consumption is more significant overall than for offices.

At the residential level, the apparent higher consumption for bathroom taps in LEED is mainly due to the fact that LEED only produces a single value for all taps (including kitchen taps) whereas BREEAM and VERDE distinguish between these. The consumption due to toilet use was very consistent between schemes but there was significant variation in consumption for showers, which is also a dominant influence on total indoor residential water consumption. There was also a significant variation in the calculated consumptions for dishwashers, although their contribution to total consumption was negligible in all cases.

In relation to office buildings, calculated consumption for BREEAM was significantly higher than the other schemes, especially due to the higher assumed use of showers. The VERDE and DGNB schemes were very similar, except for the fact that VERDE does not assume any use of kitchen taps at all.

### 5.2.1.3 Outdoor water use

The VERDE scheme has been developed for Spain, where many regions have been identified to be at a high risk of desertification. VERDE has a criterion that provides a comprehensive and detailed approach to optimising vegetated areas and irrigation systems to minimise water consumption. Uptake of this criterion has been low, with applicants perhaps being put off by the level of detail and complexity of the approach, which is likely to be simplified in subsequent versions.

BREEAM has a more open-ended approach to projects where irrigation is identified as a source of unregulated water use. Applicants are required to simply demonstrate how irrigation water demand has been reduced, for example by the use of drip-fed subsurface systems, use of greywater or harvested rainwater and careful choice native and/or low-water demand vegetation.

LEED offers a simplified approach for homes by rewarding the reduction in use of turf in vegetated areas and the increase in native or adapted plants (on a %

vegetated area basis). For non-domestic buildings, % reduction in irrigation demands during the peak watering month is identified as the key performance indicator.

The HQE criteria arguably offer the most holistic approach by also considering the permeability of the building site and rewarding schemes where rainwater is allowed to infiltrate into the ground onsite or is deliberately harvested and stored onsite with the triple purpose of reducing downstream flood risk, reducing potable water demand and implementing some degree of sediment removal from rainwater prior to it reaching natural watercourses.

#### **5.2.1.4 Greywater reuse and rainwater harvesting**

All five schemes make allowance for greywater reuse and rainwater harvesting to contribute to reductions in calculated water consumption. However, the uptake of such systems varies substantially from country to country, with cultural, legislative, policy and climatic factors playing a role.

For example, the reuse of greywater and the installation of rainwater harvesting systems were extremely low in VERDE assessed projects in Spain meanwhile rainwater harvesting is widespread in Germany even in non-DGNB certified buildings.

The use of greywater and harvested rainwater is strictly limited to non-potable uses only (for example for toilet flushing and irrigation). Some concerns in Spain have been expressed about possible health risks of greywater exposure to children in gardens.

#### **5.2.1.5 Water use in a regional context**

BREEAM's International criteria recognise the need to contextualise water requirements. Weightings are applied to water consumption requirements as a function of which "*precipitation zone*" (zone 1, 2 or 3) a building lies in.

In Spain, there is a major difference in rainfall between the north and south of the country and the VERDE criteria are considering introducing weightings linked to regional rainfall data.

To try and improve the accuracy of water consumption estimates for residential buildings in a particular country it would be necessary to divide or multiply the result derived from a calculation tool by a factor that is directly related to the national average domestic water consumption (e.g. based on the EUREAU statistics in Figure 5.1).

### **5.4.2 Progress made by scheme harmonisation initiatives**

#### **5.4.2.1 Common Metrics pilot phase 1, Sustainable Building Alliance**

The Sustainable Building Alliance's initial set of indicators (the 'Common Metrics') included one indicator relevant to macro-objective 3 – water consumption. The unit of measurement is defined as m<sup>3</sup>/time period.

The indicator may optionally include water consumed during the production of different materials and products used in buildings but must include water consumption during the use phase. Data requirements for the use phase are divided into:

- building related appliances: urinals, WCs, taps (internal and external), baths and showers.
- Building-related processes: irrigation of landscaping, cleaning (optional), greywater (negative input), rainwater (negative input).

- Appliances that are not building related: dishwashers, washing machines, water softeners, waste disposal units.

Reference is made to the use of different national calculation methods for water consumption. Data for sanitary products is to be collected from manufacturers. Further specifications are provided for sanitary fittings in commercial and residential buildings. For rainwater calculations, reference is made to British Standard 8515.

#### **5.4.2.2 CESBA Common European Sustainable Building Assessment (New public buildings v1.1)**

The CESBA assessment scheme includes one criterion on water consumption and the use of rainwater in its v1.1 indicator catalogue.

The criterion rewards the achievement of a >50% reduction in water use compared to standard fittings. Other specific installations are also rewarded: IR sensors, double WC flush, water less urinals, rainwater collection and, linked to this, rooftop greening.

## 5.5 Identification and screening of potential performance indicators

### 5.5.1 Long list of macro-objective 3 direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope			Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage	Building aspects			
<b>3.1 Operational water consumption</b>							
<b>total water consumption (during use stage)</b>	litres per person per day	B7: Operational water consumption	(Concept design) Technical design Construction	based on flow rate of sanitary appliances	<i>with reference to:</i> - assessment scheme calculation methodologies and - regulatory requirements and calculation methods	-	FS
	m <sup>3</sup> /person/year	B7: Operational water consumption	(Concept design) Technical design Construction	based on flow rate of sanitary appliances and typical occupation levels		-	FS
	points awarded on a scale for each appliance in function of l/flush for cisterns, urinals; l/minute for washbasins, showers etc..	B7: Operational water consumption	(Concept design) Technical design Construction	based on flow rate of specified sanitary appliances weighted to building occupancy		-	FS
<b>intensity of water consumption</b>	normalised to reflect occupancy rate	B7: Operational water consumption	(Concept design) Technical design	See above	-	FS	
<b>reduction of water consumption</b>	% reduction compared to reference value	B7: Operational water consumption	(Concept design) Technical design Construction		-	FS	

<b>total water consumption (during construction)</b>	litres per person per day	A4-5: Construction	Construction	-	-	-	FS
<b>3.2 Water scarcity</b>							
<b>Water Exploitation Index (WEI)</b>	% scarcity	B7: Operational water consumption	N/A	-	European Environmental Agency (EEA), Eurostat	-	CC
<b>water scarcity footprint</b>	LCA indicator	B7: Operational water consumption	N/A	function of the ratio between the total water demand and renewable water availability	AWARE (Available Water REmaining)	-	AR

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 5.5.2 Long list of macro-objective B3 supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>B3.1 Operational water consumption</b>							
<b>Flow rate of sanitary appliances</b>	l/flush; l/minute (depending on appliance)	B7: Operational water consumption	Concept design Technical design Construction	Sanitary appliances (cisterns, urinals, washbasins, showers...)			FS
<b>Proportion of rain water re-used</b>	%	B7: Operational water consumption	Concept design Technical design		-	-	FS
	m <sup>2</sup>	B7: Operational water consumption	Concept design Technical design	Surface area recovered for rainwater harvesting	-	-	FS
<b>Proportion of grey water re-used</b>	yes/no	B7: Operational water consumption	Concept design Technical design				FS
<b>Installation of water metering</b>	m <sup>3</sup>	B7: Operational water consumption	In-use				FS

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 6. Macro-objective 4a: Healthy and comfortable spaces that reduce exposure to hazards

### 6.1 Defining the macro-objective's scope and focus

#### 6.1.1 Policy and technical background to selection of the macro-objective

##### 6.1.1.1 Policies and strategies relating to indoor air quality

In the first Working Paper of this study *the EU environmental and health strategy (2003)* was identified as an important starting for a number of areas of European policy. The strategy described a 'cause-effect framework' for dealing with sources and the impact pathway of health stressors<sup>144</sup>. In particular, it sought to:

- Reduce the disease burden caused by environmental factors in the EU;
- Identify and to prevent new health threats caused by environmental factors.

The strategy highlights a range of health effects that are suspected to be related to environmental factors, with examples including respiratory diseases, asthma and allergies that are associated with indoor and outdoor air pollution.

As a follow-up to the emphasis placed on indoor air quality in the 2003 strategy, a supporting document and evidence base on promoting action for healthy indoor air was prepared<sup>145</sup>. This brought together an analysis of health impacts related to exposure to sources of indoor air pollution. This analysis highlighted the importance of both indoor and outdoor sources of pollution, including particulates from fuel combustion, building damp, bio-aerosols from outdoor air and Volatile Organic Compounds (VOCs).

Moreover, as part of this study, the process of dialogue with stakeholders and the macro-objective prioritisation exercise carried out during 2015 highlighted the importance of risk management in relation to the exposure of workers and building occupiers of both chemical and biological hazards. In this respect, the management of risks from exposure to chemicals is an objective of both the EU REACH and CLP regulatory systems.

Exposure to biological hazards such as mould is a less well developed aspect of European policy. The World Health Organisation (WHO) has sought to address the potential health impacts from exposure to damp and mould in homes<sup>146</sup>, emphasising that:

*'Exposures to biological agents indoors are a significant health hazard causing a wide range of health effects. Dampness is a strong and consistent indicator of risk for asthma and respiratory symptoms related to*

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<sup>144</sup> COM (2003) 338 final, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, A European environment and health strategy, Brussels, 11.6.2003

<sup>145</sup> Jantunen M., Oliveira Fernandes E., Carrer P., Kephelopoulous S., (2011) *Promoting actions for healthy indoor air (IAIAQ) European Commission Directorate General for Health and Consumers*. Luxembourg.

<sup>146</sup> World Health Organisation, *Protecting health from home damp and mould*, European regional office, <http://www.euro.who.int/en/health-topics/environment-and-health/Housing-and-health/risk-management-and-policy-options/protecting-health-from-home-damp-and-mould>



*indoor environmental conditions. Inadequate ventilation and structural failures as well as problems with thermal comfort are often to blame.'*

WHO recommends the development of local guidelines in climates which can contribute to the severity of problems. Further details of WHO guidance and recommendations based on best practice are summarised in Section 6.2.

#### **6.1.1.2 Exposure to chemical hazards: indoor and outdoor emissions**

Building occupiers can be exposed to a range of potential emissions of volatile and carcinogenic organic compounds. These can arise from building materials, furnishings, decorative materials, cleaning agents, humidity, combustion equipment and external air pollution.

In an air tight, modern home or office, the most significant direct emissions sources are understood to be paints and varnishes, textile furnishings, floor coverings and fit-out incorporating particle board<sup>147</sup>. For buildings with ventilation systems, indirect outdoor sources such as traffic have been identified as also being of significance to indoor air quality<sup>148</sup>.

WHO Indoor Air Quality (IAQ) guidelines exist for the level of indoor exposure levels for a number of indoor air contaminants, including PM2.5 particulates, CO, NO<sub>2</sub>, formaldehyde, benzene and naphthalene. Of these contaminants, DG Health and Food Safety (formerly DG Health & Consumers) identified fine particulate matter from outdoor air pollution and indoor combustion equipment as the most significant source of indoor exposure<sup>149</sup>.

This finding is supported by the European Collaborative Action (ECA) on 'Urban air, indoor environment and human exposure'<sup>150</sup>, the EnVIE project<sup>151</sup> and EU monitoring projects such as Officair<sup>152</sup>. A number of relevant collaborative EU studies are examined further in sections 6.2.4 and 6.3

#### **6.1.1.3 Exposure to biological hazards: dampness and mould**

In older residential buildings, as well as modern residential buildings with poor ventilation, humidity and condensation may be important considerations because, as was noted in section 6.1.1.1, they can have significant implications for the health of occupants.

Reviews of studies relating to homes suggested that around 17% of the EU population (approximately 80 million people) live in homes in which damp and associated mould growth may provoke respiratory or allergenic health effects<sup>153</sup><sup>154</sup>. Moreover, Haverinen-Shaughnessy (2012) found that the prevalence may vary by geography and climate, as illustrated in Figure 6.1.

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<sup>147</sup> Bluysen et al, *European Indoor Air Quality Audit in 56 office buildings*, Indoor Air: 1996, 6(4), p-221-228

<sup>148</sup> European Commission (2011) *Promoting actions for healthy indoor air*, DG Health & Consumers

<sup>149</sup> *ibid* 103

<sup>150</sup> JRC-IHCP, <https://ec.europa.eu/jrc/en/research-topic/human-exposure>

<sup>151</sup> EnVIE, *Co-ordination Action on Indoor Air Quality and Health Effects*, FP6 project final activity report, 10th February 2009

<sup>152</sup> Officair project, <http://www.officair-project.eu/>

<sup>153</sup> Haverinen-Shaughnessy.U, Prevalence of dampness and mould in European housing stock, *Journal of exposure science and environmental epidemiology* (2012) 22, 461-467

<sup>154</sup> Fraunhofer IBP, *Towards an identification of European indoor environments' impact on health and performance*, Germany, 5th December 2014

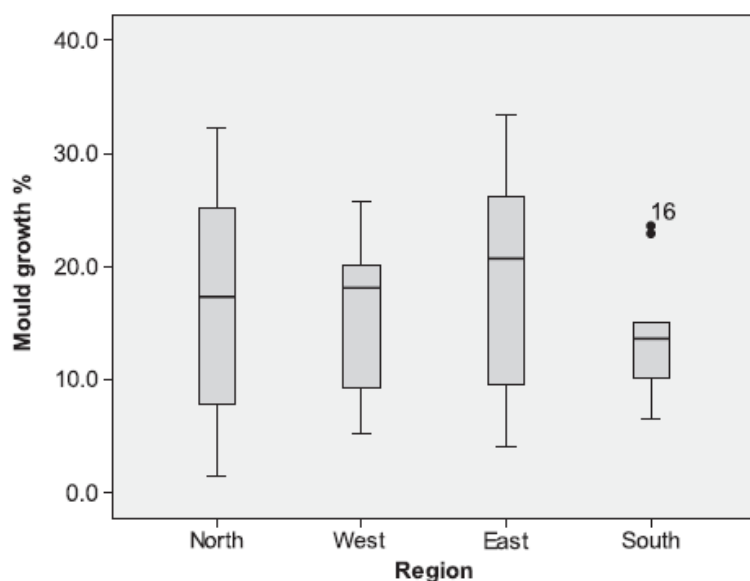


Figure 6.1. Prevalence of damp and mould in the European housing stock

Source: Haverinen-Shaughnessy (2012)

### 6.1.2 The intended scope and focus

The macro-objective is to protect human health by minimising the potential for occupier and worker exposure to health risks resulting from the design, construction and renovation of buildings.

In practical terms, the macro-objective will focus on occupant exposure to hazardous substances, which can relate to ventilation intake (particularly for buildings with active or mixed mode ventilation) or to emissions from internal fit-out materials and surface finishes/coatings.

For the renovation of domestic properties, emissions from renovation materials, as well as the presence of damp and mould (biological hazards), have additionally been identified as significant health issues that should be considered within the scope.

The potential for the exposure of workers installing or dismantling building materials should also be taken into account – although this could be linked to the avoidance of hazardous materials in the first place.

## 6.2 Cross-cutting scoping and investigation of the macro-objective's implementation

### 6.2.1 National and regional initiatives

In this section, a brief overview is provided of pioneering building level assessment schemes in Germany and Finland, the development of voluntary building product labelling across the EU, the novel new focus of attention of intrinsic hazardous properties, and initiatives to address damp and mould in housing stock. A review of selected regulatory requirements is provided in Section 6.2.2.

#### 6.2.1.1 The Building Biology Testing methods, Germany

The Building Biology Testing method was introduced in 1992 by the Institute of Building Biology and Sustainability in Germany<sup>155</sup>. It was conceived as a multi-

<sup>155</sup> Institut für Baubiologie & Nachhaltigkeit, *Standard of building biology testing methods*, SBM 2015 version

disciplinary approach to the assessment of the health of buildings. It comprehensively addresses three sub-categories of '*critical indoor environmental influences*':

- a. Fields, waves and radiation
- b. Indoor toxins, pollutants and indoor climate
- c. Fungi, bacteria and allergens

Sub-criteria are defined under each area which provide specifications for the measurement of a range of different hazardous substances and pollutants of the indoor environment. Guideline values are not provided in all cases. Sub-category b addresses the following aspects:

1. Formaldehyde and other toxic gases
2. Solvents and other VOCs
3. Pesticides and other SVOCs
4. Heavy metals and other similar toxins
5. Particles and fibres
6. Indoor climate

Sub-category c provides specifications for the measurement of moulds, their spores and metabolites (such as MVOC and mycotoxins). These requirements combine a focus on visible inspections, air humidity, water on materials with the analysis of mould and spore cultures from surfaces, dust and indoor air. The methodology emphasises the importance of comparing results with those from ambient outdoor air and uncontaminated rooms.

Of potential relevance to residential buildings are the supplementary Evaluation Guidelines for Sleeping Areas <sup>156</sup>, which are specifically developed to address additional sensitivities relating to exposure during sleep. It provides guideline values for emissions and pollutants, and has a four level grading system based on the level of precaution and risk, ranging from 'no concern' to 'extreme concern'.

#### **6.2.1.2 The Finnish classification of the indoor environment**

The Finnish classification of the indoor environment is a voluntary system for the classification of indoor environments in new and renovated buildings. It aims to support moves towards healthier and more comfortable buildings. It was first established in 1995 and revised in 2001 and 2008 <sup>157</sup>, and is considered a pioneer in making the link between building product emissions into the indoor environment and the resulting indoor air quality.

The classification specifies target and design values for an indoor climate. The system comprises three main components:

- Target values for indoor quality (S) linked to EN 15251 and including indoor air;
- Guidance for design and construction (P) including structural design, and water and moisture control;
- Requirements for building products (M) including emissions classes.

The overall approach is that building product choice (M) should be prioritised before adjusting other parameters such as ventilation (S). Those aspects considered relevant to macro-objective B4a are summarised in table 6.1.

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<sup>156</sup> Institut für Baubiologie & Nachhaltigkeit, *Building biology evaluation guidelines for sleeping areas - Supplement to the Standard of Building Biology Testing Methods*, SBM 2015 version

<sup>157</sup> Finnish Society of Indoor Air Quality and Climate (2008) *Classification of indoor environment – target values, design guidance and product requirements*.

Table 6.1 Overview of the Finnish classification of the indoor environment

Components	Aspects covered	Requirements
Target values for indoor quality (S)	<ul style="list-style-type: none"> <li>- EN 15251, Appendix B1.2 Categories for non-residential ventilation rates</li> <li>- EN 15251, Appendix B1.3 Categories for non-residential ventilation rates</li> <li>- S1-3 categories for CO<sub>2</sub>, radon and 'stability' of the environment</li> </ul>	<p><i>No thresholds for chemical or biological hazards</i></p> <p>Implied restriction on Class M2 and M3 building materials</p>
Guidance for design and construction (P)	<ul style="list-style-type: none"> <li>- Surface designs taking into consideration building material emissions</li> <li>- Moisture characteristics that conform with the intended use</li> <li>- Water and moisture control plan during construction works</li> </ul>	>80% interior surfaces are emissions class M1 rated building materials
Requirements for building products (M)	<ul style="list-style-type: none"> <li>- Selection of interior building materials based on their emissions class performance (with reference to P)</li> <li>- Supply air filter specification according to EN 13779</li> </ul>	<p>M1 emissions class performance:</p> <ul style="list-style-type: none"> <li>- TVOC emissions 0.2 mg/m<sup>2</sup>/hr (70% identification of compounds)</li> <li>- Formaldehyde 0.05 mg/m<sup>2</sup>/hr</li> <li>- Ammonia 0.03 mg/m<sup>2</sup>/hr</li> <li>- Carcinogenic compounds 0.005 mg/m<sup>2</sup>/hr</li> </ul> <p>M2 emissions class performance:</p> <ul style="list-style-type: none"> <li>- TVOC emissions 0.4 mg/m<sup>2</sup>/hr (70% identification of compounds)</li> <li>- Formaldehyde 0.125 mg/m<sup>2</sup>/hr</li> <li>- Ammonia 0.06 mg/m<sup>2</sup>/hr</li> <li>- Carcinogenic compounds 0.005 mg/m<sup>2</sup>/hr</li> </ul>

Source: Finnish Society of Indoor Air Quality and Climate (2008)

### 6.2.1.3 European building product emissions labelling

A range of labelling schemes for the emissions from building materials and products have emerged during the last 20 years. These have the objective of protecting building users and occupants from health hazards by encouraging (or requiring) source control strategies that control building material emissions.

An overview of the existing labelling schemes in the EU and moves towards harmonisation is provided by the JRC's European Collaborative Action (ECA) Report 27, which forms the basis for this short overview and characterisation of EU schemes.

#### 6.2.1.3.1 Types of risk management strategies used by labelling schemes

ECA 27 identified the following types of risk management strategies as being used in existing voluntary labelling schemes and Member State policies:

- Restriction of hazardous substances (content);
- Thresholds for hazardous emissions;

- Restriction of Carcinogenic, Mutagenic and toxic for Reproduction (CMR) substances;
- Thresholds for CMR emissions:
  - LCI-approach (Evaluation by comparison with 'Lowest Concentration of Interest')
  - LCI with limits for 'non accessible substances'
- Total VOC-approach based on threshold limits
  - Sensory evaluation
  - Information dissemination.

Figure 6.2 provides a simplified comparison of the most common approaches taken by EU schemes.

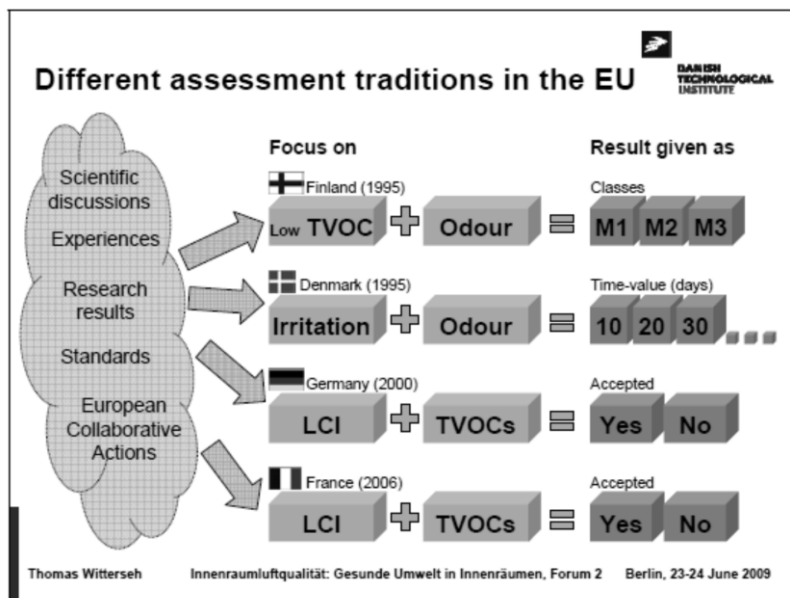


Figure 6.2 Indicative comparison of emissions assessment approaches adopted by indoor product labelling schemes

Source: JRC (2010)

An overall threshold for VOC emissions is the most commonly used strategy. While TVOC *per se* is not directly linked with health outcomes, a low limit value for TVOC indicates that the risk for any harmful emissions will be low. Health based source control has tended to focus on a LCI 'Lowest Concentration of Interest' values for specific substances of concern.

In several cases TVOC is complemented with thresholds or restrictions that apply to selected CMR substances such as formaldehyde, as well as odours and irritants to which humans are sensitive. The latter has been shown to be important because chemical characterisation of emissions is not a good predictor of sensory effects<sup>158</sup>.

### 6.2.1.3.2 Background to current EU labelling schemes

Of the schemes available in the market, some have been developed as voluntary initiatives by industry or NGOs (e.g. GUT, EMICODE, M1, Danish Indoor Climate

<sup>158</sup> Salthammer, T., Bahadir, M.,. *Occurrence, Dynamics and Reactions of Organic Pollutants in the Indoor Environment* (2009). CLEAN - Soil, Air, Water, Volume 37, 6, 417 – 435.

*Label*), whilst some have been mandated by regulation (e.g. *French emissions classes, Belgian VOC Regulation, German AgBB*). .

The JRC has highlighted the significant reductions in material emissions that have been driven by such schemes – many of which started as voluntary initiatives. For example, Finland's M1 voluntary labelling system has over 1,500 products that meet the criteria. The emissions from these products are (as estimated by a material testing laboratory) approximately one fifth of the level they were in the early 1990's. In Denmark, similar the 'Danish Indoor Climate Label' has played a similar role.

Several labelling schemes can be seen to now have a strong position in local markets and, moreover, are recognised by industry as well as actors within the construction industry. Mature schemes now also provide access to many thousands of products, making them more accessible.

A number of schemes have been endorsed by governments and/or now have a mandatory status, although progress has in part been restricted by the lack of uncertainty on the causal relationship between hazards and exposure risks. This makes it very difficult to assess the effectiveness of source control policies.

The German AgBB (Committee for Health-related Evaluation of Building Products) scheme is one such example. In Germany, emission tests became mandatory from since October 2004 for floor coverings. Requirements followed for other product groups such as wall coverings, lacquers and other coatings for parquets, adhesives and underlays.

In France, the government policy *Le Grenelle Environnement* (2007) defined very ambitious objectives for the building sector which included taking into account of Indoor Air Quality in building designs. The result was the introduction of requirements for the mandatory labelling of VOC emissions for building and decoration products. The labelling system is based on an emissions class rating, which includes performance requirements for total VOCs and ten Carcinogenic, Mutagenic and toxic for Reproduction (CMR) substances.

#### **6.2.1.4 The Green Screen hazard assessment system, USA**

There is a trend in some product sectors and chemical regulatory systems to carry out hazard evaluation of functional chemicals to inform decisions on investments in safer substitutes. Green Screen is a US hazard assessment tool that has been developed by the NGO Clean Production Action <sup>159</sup>.

Green Screen is based on the Global Hazard System (GHS) for classification of substances. It consists of a four level benchmarking of hazards ranging from 'avoid – chemical of high concern' to 'prefer – safe chemical', with end points focussing on hazards relating to human toxicity and ecotoxicity, as well as properties of persistence and bioaccumulation. The methodology is based on a system of hazard assessment developed by the US Environmental Protection Agency (EPA).

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<sup>159</sup> Clean Production Action (2013) *Green Screen chemical hazard assessment procedure v1.2, USA*

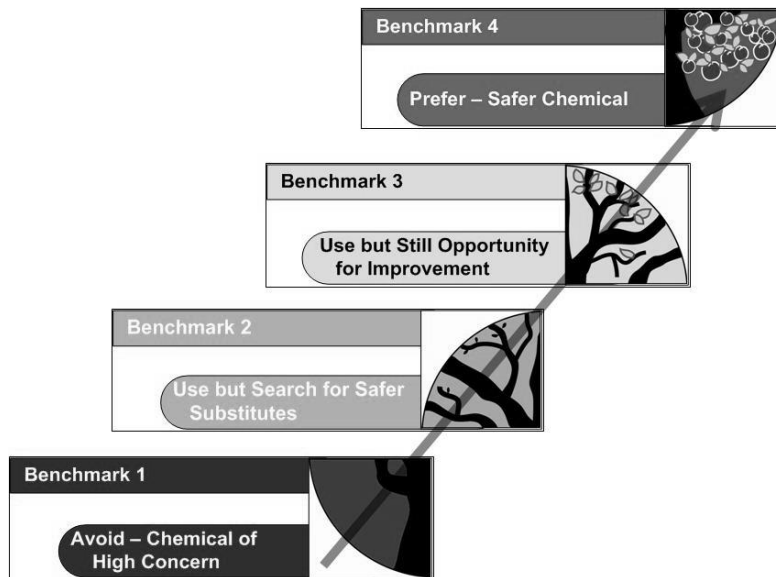


Figure 6.3 Green Screen hazard assessment system benchmark levels

Source: Clean Production Action (2015)

Green Screen is now used by a number of major companies and was recently used by the Danish EPA to evaluate flame retardants. Notably, it was introduced into the LEED building certification system as part of the latest revision released in 2015, where it can be used to make hazard assessments of building products<sup>160</sup>.

### 6.2.1.5 Action to address damp and mould

#### 6.2.1.5.1 Moisture and mould programme, Finland

In 2010, the Finnish Government launched a national program to combat moisture and mould issues in the Finnish building stock<sup>161</sup>. It was a joint initiative under the coordination of the Finnish Ministry of the Environment, involving multiple disciplines: not only other ministries and central government actors were involved, but also: local municipalities; the building industry; research organisations; housing and homeowner associations; and property developers amongst others.

The program was originally foreseen to run from 2010 to 2014, but it was extended for two additional years due to its success. The action plan taken forward under the programme has consisted of six main focus areas:

1. New building projects and renovation construction;
2. Repair of moisture and mould damage;
3. Education & training, qualification, and research;
4. Housing trade and advisory services;
5. State properties and workplaces;
6. State aid systems.

The main outcomes of the programme has been awareness raising and the sensitising of citizens to the issue of moisture and mould in the indoor built environment in Finland.

Linked to the programme efforts were made to develop methods to analyse samples within buildings in order to diagnose the presence of mould. The three

<sup>160</sup> US Green Building Council, *How to use Green Screen in LEED v4*, Press release, 21st October 2015, <http://www.greenscreenchemicals.org/news/article/how-to-leed-guide-press-release>

<sup>161</sup> Moisture and mould programme, *Programme information*, Ministry of the Environment, Finland <http://uutiset.hometalkoot.fi/en/programme-information.html>

year TOXTEST research project was led by the Ministry of Social Affairs and Health, and sought to identify whether dust samples could be used to diagnose and prioritise action in properties<sup>162</sup>. The study was not successful because the sampling method was not able to distinguish infested samples from those of a control group.

#### **6.2.1.5.2 Mould Severity Index (MSI), English Housing Condition Survey**

The English Housing Condition Survey (EHCS) was a major survey carried out every four years of the condition of the English housing stock. During the existence of the Warm Front home energy efficiency programme in the UK between 2000 and 2013, the EHCS included building surveys to assess moisture levels, wall surface temperatures and the presence of damp and mould<sup>163</sup>.

A Mould Severity Index (MSI) was used to quantify the presence of damp and mould. The MSI relies on visual inspection by a qualified expert with the scoring methodology consisting of three elements:

- Prevalence: 1 point is allocated per room where mould is present;
- Severity: for each room 1 or 2 additional points are allocated based on the 'moderate' or 'severe' mould presence;
- Communal space: An additional 1 point is allocated if mould is present in a living room.

Surveys carried out in 1996 and 2001 revealed that approximately one in five properties surveyed had mould problems<sup>163</sup>. Later analysis of EHCS survey results to inform improvements to UK building regulations suggested that mould formation did not only relate to relative humidity levels in dwellings, but localised problems such as thermal bridging and air gaps.

#### **6.2.1.5.3 Housing Health and Safety Rating System (HHSRS), UK**

The UK introduced in 2000 a definition of what constitutes a 'decent home'. This formed the basis for a programme to improve the condition of all public housing by 2010. A decent home must meet the minimum standards in the Housing Health and Safety Rating System (HHSRS)<sup>164</sup>.

To be 'decent', a home must not contain a category 1 hazard as assessed by the HHSRS. Damp and mould growth is amongst the listed hazards. Mould spores are cited as having the potential to be allergenic, carcinogenic, toxic or to cause infections. Toxins can also cause breathing problems, nausea and diarrhoea. The rating system has four levels depending on the severity and duration of potential harm:

- Class 1: Extreme harm outcomes;
- Class 2: Severe harm outcomes;
- Class 3: Serious harm outcomes;
- Class 4: Moderate harm outcomes, but are still significant enough to warrant medical attention

The HHSRS highlights that hazard assessment relies on professional judgement because of the number of possible causal factors. The location, extent and duration of the dampness will be important factors.

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<sup>162</sup> Moisture and mould programme, TOXTEST completed - no new method discovered for identifying mould infestations, Ministry of the Environment, Finland <http://uutiset.hometalkoot.fi/en/home/education-training-qualification-and-research.html>

<sup>163</sup> Altamirano-Medina.H, Davies.M, Ridley.I, Mumovic.D, Oreszczyn.T and M.Ucci, *Moisture performance criteria for UK dwellings*, University College London, Paper submitted to IEA Annex 41 meeting, April 2006

<sup>164</sup> UK Government, *Housing Health and Safety Rating System – Operating guidance*, Housing Act 2004 guidance.



## 6.2.2 Building permitting and planning requirements

### 6.2.2.1 Building regulations addressing humidity and thermal bridging

Building regulations in a number of member states seek to address the causal factors for damp and mould. For example, in Poland, there is a focus on the temperature of the inner surfaces of external walls. A thermal co-efficient level is specified to prevent condensation. In Sweden, buildings must be designed to avoid moisture conditions that can result in damage, smell or the appearance of mould. Maximum moisture conditions are laid down.

### 6.2.2.2 Action to address Indoor Air Quality

The Building Performance Institute Europe (BPIE) analysed residential building indoor air quality regulations in eight Member States<sup>165</sup>. The eight Member States covered by the study were Belgium (Brussels Capital Region), Denmark, France Germany, Italy, Poland, Sweden and the UK (England and Wales).

Table 6.2 summarises requirements that focus on indoor air quality. They comprise different strategies and measures to:

- Reduce source emissions from building products;
- Establish maximum thresholds for pollutants that are harmful to health;
- Reduce source emissions from heating and cooking appliances;
- Avoid the buildup of moisture and the potential for formation of mould;

In Denmark and France, the requirements are linked to labelling systems for building products. Although Germany sets no specific legal requirements, the AgBB labelling system and other ecolabels are commonly used. Poland and Denmark have specified requirements relating to the use of coal by-products in cement and glass fibres in insulation.

Table 6.2 Selected national requirements for indoor air quality

Country	Scope of requirements	Thresholds
Belgium (Brussels capital region)	<ul style="list-style-type: none"> <li>- Minimum air quality level INT3</li> <li>- Selection of materials to avoid pollutants</li> <li>- Use of low sulfur fuels</li> </ul>	TVOC <100 µg/m <sup>3</sup> (30 minutes exposure) Toluene 260 µg/m <sup>3</sup> Xylene 870 µg/m <sup>3</sup>
Denmark	<ul style="list-style-type: none"> <li>- Building materials shall have the lowest possible pollutant emissions</li> <li>- Reference to Danish Indoor Climate Labelling scheme</li> <li>- Construction product formaldehyde class E1 shall be met</li> <li>- Mineral wool containing materials must not emit fibres into indoor environment</li> <li>- Fly ash and coal firing slag building bases must be covered to a specified depth and weight</li> </ul>	Formaldehyde <0.1 mg/m <sup>3</sup>
France	<ul style="list-style-type: none"> <li>- Mandatory labelling of building products was introduced in 2011</li> </ul>	Trichloroethylene <1 µg/m <sup>3</sup> Benzene <1 µg/m <sup>3</sup> DEHP <1 µg/m <sup>3</sup> DBP <1 µg/m <sup>3</sup>
Germany	<i>No specific legislation for pollutant emissions</i>	<i>No thresholds specified</i>

<sup>165</sup> BPIE (2015) *Indoor air quality, thermal comfort and daylight – analysis of residential building regulations in eight EU member states.*

Italy	No specific limit values are defined for indoor air quality as a whole <ul style="list-style-type: none"> <li>- Formaldehyde limit value applies in particular to envelope material made of wood</li> <li>- Potential surface or interstitial condensation shall be avoided and verified</li> </ul>	Formaldehyde <0.124 mg/m <sup>3</sup>
Poland	The following substances are restricted: <ul style="list-style-type: none"> <li>- Acrylamide</li> <li>- Acrylonitrile</li> <li>- Chloramine</li> <li>- Carbon tetrachloride</li> <li>- Cadmium (as a pigment additive)</li> <li>- Lead (as a pigment additive)</li> <li>- Ash and slag from coal firing</li> </ul> The following for internal use: <ul style="list-style-type: none"> <li>- Chlorophenol</li> <li>- Farbasol</li> <li>- Ethylene glycol</li> </ul>	Thresholds are strictest for residential and other private buildings: Benzene (0.1% w/w) 10-20 µg/m <sup>3</sup> Xylene, toluene, ethylobenzene and ethyloeksen (20% w/w) 100 – 250 µg/m <sup>3</sup> Chlorohydrocarbons (5% w/w) 150 - 200 µg/m <sup>3</sup>
Sweden	Micro-organisms shall not affect the indoor air to the extent that they harm human health	<i>No thresholds specified</i>
UK	There should be no visible mould on external walls	TVOC <300 µg/m <sup>3</sup> (8 hour average)

Source: BPIE (2015)

## 6.2.3 Private and public sector building practices

### 6.2.3.1 Studies of moisture damage in existing homes

Haverinen et al (2001) report on the results of surveys of 630 randomly selected homes in Finland<sup>166</sup>. The surveys served as a proxy for the potential for mould exposure. The building surveys were accompanied by occupant questionnaires which sought to analyse the association between moisture damage and occupant health.

In order to interpret the building survey findings, a three level classification system was developed to grade the severity of moisture damage. The classification system was tested for the dose-response relationship between the damage and occupant health effects.

The main finding was that although the reliability of determining potential exposure could be improved – for example by developing direct fungi measurements – the validity of indirect (proxy) methods was shown for a number of dose response relationships. Moreover, the accuracy could be further improved by ensuring that those carrying out the surveys are suitably trained and use pre-designed checklists.

<sup>166</sup> Haverinen.U, Husman.T, Vahteristo.M, Koskinen.O, Moschandreas.D, Nevalainen.A and Pekkanen.J, Comparison of two-level and three-level classifications of moisture-damaged dwellings in relation to health effects, *Indoor Air*, 11 (2001) 192-199

Table 6.3 Classification criteria for the severity and amount of moisture damage

Grade I	Grade II	Grade III
<ul style="list-style-type: none"> <li>No visible moisture damage recorded</li> <li>Minor moisture damage, but no further consequences expected</li> <li>One patch of deteriorated interior finish or covering which needed repairing</li> </ul>	<ul style="list-style-type: none"> <li>Single observation of a damaged interior structural component that needed opening, drying and renewal or minor repair</li> <li>Single patch of deteriorated interior finish or covering, as in Grade I, plus other damage of the same or lower severity</li> </ul>	<ul style="list-style-type: none"> <li>The presence of a damaged interior structural component, as in Grade II, together with other damage of the same level of severity or less</li> <li>A functional element that needed partial or total renewal, together with or without the presence of other damage</li> </ul>

### 6.2.3.2 Studies of the monitoring of completed works

#### 6.2.3.2.1 Indoor air quality with a focus on chemical exposure

Indoor air investigations as well as emission measurements from building materials in test chambers have been performed extensively in recent decades. Investigations on exposure to indoor (and outdoor air) pollutants have focused on source identification by using different source apportionment models (e.g. Sexton and Hayward 1987<sup>167</sup>).

However, there are very few investigations on emissions measured on site from real finished structures. A study was conducted by the Finnish research institute VTT<sup>168</sup>, and examined indoor air concentration levels and emissions in new residential buildings that represent the current building practice in Finland, and in which low-emitting building materials were used.

Emissions of structures were determined on site from the real finished structure and the impact of them on the concentration levels was clarified. Indoor air concentrations and emissions from structures and interior materials were investigated in eight residential buildings during the time of construction and the first year of occupancy. Volatile organic compounds (VOCs), formaldehyde and ammonia concentrations and emissions as well as temperature, humidity, and ventilation were measured.

The study was linked to the Finnish Indoor Climate Classification in Finland. It was introduced in 1995 and revised in 2000<sup>169</sup>. The classification defines the design and target values for thermal comfort, ventilation, odour intensity, noise levels, concentration of indoor air pollutants, material emissions and components of ventilation systems.

The classification also provides procedures for constructions work in new buildings (S, M and P classes). Though the classification is voluntary, the use of M1-classified, low-emitting materials has markedly increased and probably improved

<sup>167</sup> Sexton, K. and Hayward, S. B. 1987. *Source apportionment of indoor air pollution*. Atmospheric Environment 21, 407-418

<sup>168</sup> Järnström, H. *Reference values for building material emissions and indoor air quality in residential buildings* [Referenssiarvot rakennusmateriaalien emissioille sekä sisäilman laadulle asuinrakennuksissa]. Espoo 2007. VTT Publications 672. 73 s. + liitt. 63 s.

<sup>169</sup> FiSIAQ, Finnish Society of Indoor Air Quality and Climate: Classification of Indoor Climate 2000. Espoo, 2001

the Indoor Air Quality (IAQ) in new Finnish buildings. To date, there are over thousand M1-classified building products on the market.<sup>170</sup>

The study confirmed that the Finnish material classification system provides a basis to achieve good indoor air quality when comparing to the target values for pollutant concentrations given by the classification in real buildings.

Recommendations were also made for its further development. Based on the indoor air and emission results, reference values, i.e. “normal” and “abnormal values, were defined for the six- and twelve month-old buildings.

#### **6.2.3.2.2 Indoor air quality with a focus on biological exposure**

The World Health Organisation (WHO) has documented case studies of mould remediation in housing from the Germany, Finland, France, Slovakia, Sweden and the UK<sup>171</sup>. These provide results and recommendations for policy. The WHO has also published guidelines on dampness and mould that address the evaluation of human risk<sup>172</sup>.

As was described in section 6.2.1.5, Finland has made moisture and mould a focus for attention. Haverinen et al (2008) carried out a study of seven buildings in Finland which had been the subject of mould remediation works<sup>173</sup>. These included an office and a complex of row houses. The aim was to develop a methodology for assessing the success of the remedial actions.

Initial observations of the causes of the damp and mould problems highlighted a number of factors:

- Poor ventilation;
- Air leakage through structures;
- Local areas of moisture damage; and,
- Raised moisture levels in floors and walls.

The process combined initial assessment prior to the remediation actions being carried out, followed by post-completion (2 months) and occupancy monitoring (6 months – 4 years following completion). The remedial actions included the sealing of air leakage paths, localised improvement of insulation, improved ventilation (including in bathrooms) and the drying of wet materials.

The study found that it was possible to monitor the results of a remediation using a number of methods and metrics. In the cases of the office and residential buildings monitored, the common investigation methods used were a visual inspection, analysis of air samples for microbial concentrations, surface moisture detection, measurement of relative humidity from structures and of air, and the opening and dismantling of structures for testing. In addition, occupant questionnaires, clinical diagnosis and biomarkers were used to evaluate health effects.

In terms of the validity of the methods used, the following conclusions were reached:

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<sup>170</sup> The Finnish Building Information Foundation, 2007. <http://www.rts.fi>

<sup>171</sup> World Health Organisation (2008) *Interventions and actions against damp and mould - a review of case studies*, WHO regional office for Europe.

<sup>172</sup> World Health Organisation (2009) *WHO guidelines for indoor air quality – dampness and mould*, WHO regional office for Europe.

<sup>173</sup> Haverinen-Shaughnessy.U, Hyvarinen.A, Putus.T and N,Nevalainen, *Monitoring success of remediation: Seven case studies of moisture and mold damage buildings*, Science of the total environment, 399(2008) p.19-27

- Standard building evaluation methods were considered to be the most applicable method;
- Microbial analysis is more problematic because of potential background levels and acceptable thresholds. The timing (according to the season) and the cost of sampling are also important factors.
- Questionnaires were considered to be valid, but it is important to follow established best practice in the organisation, design and timing of surveys.

#### **6.2.4 Collaborative EU projects**

As part of the field study selection a number of collaborative EU projects are analysed in order to identify lessons for office buildings (Officair:FP7), new-building residential buildings (Cleanair, lowenergy) and renovated residential buildings (Renovair, INSULAtE: LIFE).

In this section, a number of knowledge sharing collaborative EU project that have produced guidelines on indoor air quality are reviewed. The project HealthVent is considered to be of particular relevance because of the range of stakeholders that are engaged and the holistic approach to health-based ventilation strategies. The project HITEA had a specific focus on dampness, moisture and mould as an emerging environmental health issue.

##### **6.2.4.1 HealthVent (Health-Based Ventilation Guidelines for Europe)**

The HealthVent project on Health-Based Ventilation Guidelines for Europe was launched in 2010 under the 2<sup>nd</sup> Programme of Community Action in the Field of Health (2008-2013) <sup>174</sup>. It ran from 2010 to 2013 with the objective of developing guidelines for health-based ventilation for buildings in Europe, including offices and residential buildings within its scope. The health-based ventilation guidelines also took into account energy efficiency aspects such as, for example, air tightness.

The study put forward an application strategy that could provide a useful framework for a composite set of EU indicators on indoor air quality <sup>175</sup>. The strategy places a priority on source control - including factors relating to a buildings location, materials specifications and maintenance - and with adjustment of ventilation rates as a last resort to control indoor exposure - based on occupancy levels and the extent of source control.

Figure 6.4 provides an overview of the application strategy, which consists of three 'air systems':

- I. Outdoor air: Air entering the building should respect WHO air quality guidelines. Influences will include building location, air intake location and air tightness. Air cleaning may be required if the outdoor air does not respect WHO guidelines.
- II. Building: Air inside a building may be contaminated by other pollutants from indoor sources. These sources can include building materials, equipment, local exhaust (e.g. cooking, washing) and consumer products. Indoor source control is required to address these different potential sources. For example, building material selection based on tested emissions levels.
- III. Health-based ventilation rate: If potential sources can be controlled then only human pollutants (CO<sub>2</sub>, moisture) will require control according to a

<sup>174</sup> HealthVent, Project website hosted by the Technical University of Denmark, <http://www.healthvent.byg.dtu.dk/>

<sup>175</sup> De Oliveira Fernandes.E, *Guidelines for health-based ventilation – holistic approach and strategies*, IDMEC-FEUP, Final project presentation given in Brussels, 20<sup>th</sup> February 2013

'reference minimum ventilation rate'. This is proposed as 4 l/s/per, but with adjustment upwards to control remaining sources.

With respect to component I of the system, EN 13779 is of particular relevance, linking Outdoor Air Quality (ODA) on a three point rating with recommended filter classes based on EN 779, which is cross referenced with a four level Indoor Air Quality (IDA) rating.

For component II of the system, and related to the control of damp and mould, indoor source control in residential buildings may entail localised adjustment of ventilation rates in areas that generate high levels of humidity – such as kitchens and bathrooms.

The proposed 'reference minimum ventilation rate' is the minimum rate laid down in EN 15251 – as reflected in Category IV (non-residential) and Category III (residential).

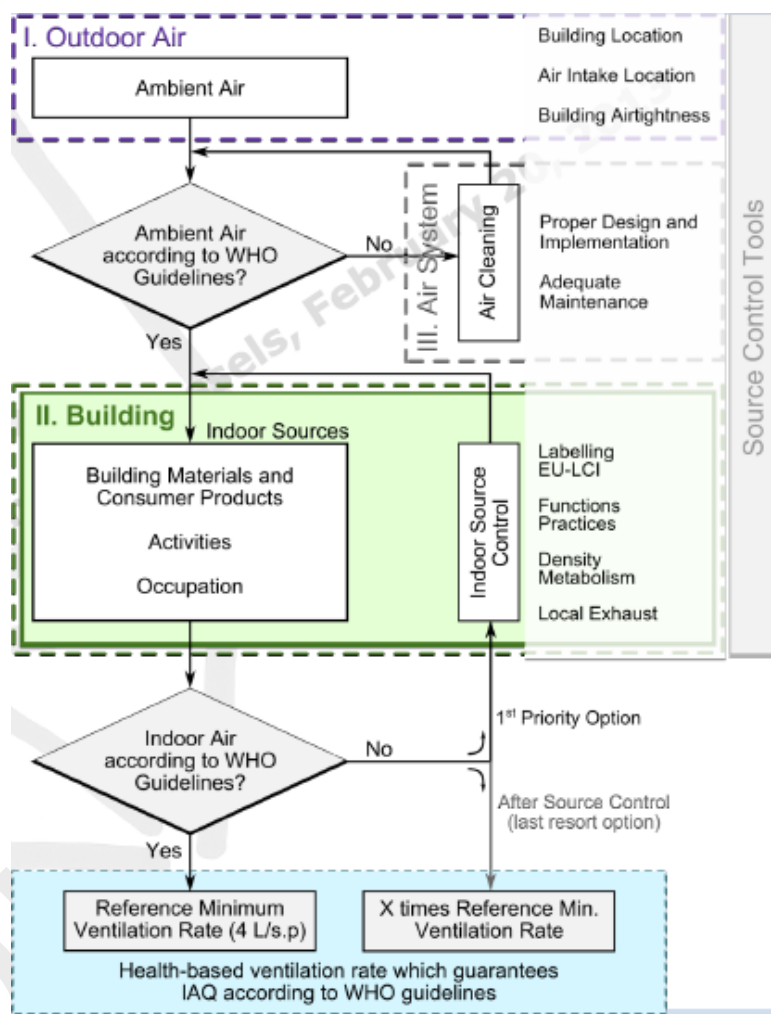


Figure 6.4 HealthVent decision diagram

Source: HealthVent (2013)

#### 6.2.4.2 INSULAtE, Life+

INSULAtE is a European project, co-financed by the EU Life+ programme. The research objectives, methodologies applied and indicators assessed in INSULAtE are similar to the ones covered in Renovair (see Section 6.3.4), but while

Renovair focusses on the relation of energy efficient renovations in the Belgian (Central-European) context, INSULAtE focusses on this relation in a Northern-European context.

Furthermore, the buildings studied in INSULAtE are mostly multi-family houses or apartment buildings (built in the period 1960-1980), in contrast to the single family houses covered in Renovair. Assessments were performed in a total of 46 Finnish and 20 Lithuanian apartment buildings (about 5 apartments per building) on two occasions: 1st assessment at the baseline (before retrofits in the case buildings) and 2nd (followup) assessment (after retrofits in the case buildings). Assessments were performed mainly during the heating seasons.

Assessment included the following measurements of Indoor Environmental Quality (IEQ) indicators that may impact the health and wellbeing of residents<sup>176</sup>:

- Indoor temperature (T) and relative humidity (RH)
- Air change rate (ACR)
- Carbon dioxide (CO<sub>2</sub>) and carbon monoxide (CO)
- Particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>)
- Nitrogen dioxide (NO<sub>2</sub>)
- Volatile organic compounds (VOC)
- Formaldehyde (CH<sub>2</sub>O)
- Radon
- Microbes and fibres in settled dust.

In addition, information was gathered from the occupants by using self-administered housing and health questionnaires and diaries. The questionnaire included 49 questions, mainly related to the dwelling and its surroundings, hygiene, indoor environmental issues, and health and wellbeing. The diary was filled once a day for a two-week period, and it included questions about time spent in the home and undertaking activities (such as opening windows for ventilation).

A key finding was that the majority of the apartments fulfilled the national guideline values for IEQ parameters, but that after the retrofits some indoor pollution sources emerged. This indicates that special attention should be paid to the source control of pollutants that may arise from retrofit interventions within a building.

#### **6.2.4.3 HITEA (Health effects of indoor pollutants: Integrating microbial, toxicological and epidemiological approaches)**

HITEA – *Health Effects of Indoor Pollutants: Integrating microbial, toxicological, and epidemiological approaches* – was a collaborative EU study, co-funded under the Seventh Framework Program (FP7)<sup>177</sup>. The HITEA study identified the role of indoor (biological) agents that lead to long term respiratory, inflammatory and allergic health impacts. Children's health was emphasised in the project, and a focus was put on microbial exposure due to dampness and mould problems in buildings.

The first part of the study focused on dampness and moisture problems and associated exposures to biological agents in schools. An extensive field study in schools was implemented during two school years in Northern, Central and Southern Europe (i.e. in Finland, The Netherlands and Spain respectively). This

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<sup>176</sup> Haverinen-Shaughnessy U., Turunen M., Du L., Leivo V., Kiviste M., Aaltonen A., Prasauskas T., Martuzevicius D. (2016) *Improving energy efficiency of multi-family buildings, impacts on indoor environmental quality and health*, THL

<sup>177</sup> HITEA project, *Health Effects of Indoor Pollutants: Integrating microbial, toxicological and epidemiological approaches*, funded under the EU Seventh Framework programme, [http://cordis.europa.eu/project/rcn/87924\\_en.html](http://cordis.europa.eu/project/rcn/87924_en.html)

study provides data on short term health effects which potentially lead to long term and chronic health impacts.

The second part of the study focussed on the long term health impacts of biological agents on children and adults in homes. For this part of the study, HITEA integrated results from on-going children cohorts from Spain (INMA-Menorca cohort), The Netherlands (PIAMA), Germany (LISA) and Finland (LUKAS), as well as from the European Community Respiratory Health Survey (ECRHS) adult cohort. A cohort is understood to be a group of people with defined characteristics who are followed up to determine between risk factors and health effects and is a term frequently used in the domain of medicine, particularly epidemiology<sup>178</sup>. Exposure data from different time points during life are combined with the comprehensive information on children's and adults' health already collected in these population cohorts.

The third part involved the development of a common assessment methodology for dampness and mould, including standard protocols for the data collection and a centralised database. This comprehensive database contains data on indoor exposures and related health impacts to biological and other indoor pollutants in schools and homes across Europe. The quality of the databases is based on the harmonised sample collection techniques, sample logistics and storage, and on centralised laboratory analyses to minimise inter-laboratory variation.

## **6.2.5 Standards and harmonisation initiatives**

### **6.2.5.1 The development of harmonised substance LCI and product emissions class systems**

The monitoring and control of emissions from priority chemicals, including Volatile Organic Compounds (VOC's), has been the focus of action at EU level. Work is ongoing to support the CE marking of products under the Construction Products Regulation with two relevant areas of focus - the harmonisation of health-based evaluations of emissions from construction products and the development of a harmonised EU emissions performance class system for reporting to consumers.

This work led to the publication in early 2014 of harmonised, interim Lowest Concentration of Interest (LCI) values for VOC and SVOC substances and compounds of concern are based on the existing German AgBB and French ANSES systems which apply to construction and fit-out materials<sup>179</sup>.

Whilst the LCI system provides a robust basis for substance-specific restrictions, there does not always appear to be equivalence between this approach and current product labelling schemes originating from Nordic countries, Germany, Austria, France and the USA, which combine substance-specific LCI's with overall thresholds for VOC and SVOC emissions<sup>180</sup>.

Work to establish harmonised performance classes for emissions from products has been facilitated by JRC IHCP and DG GROW, bringing together representatives from Germany, France and Belgium<sup>181</sup>. A proposal for a harmonised system will shortly be put forward, and will reflect a combination of

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<sup>178</sup> Morabia A. *A History of Epidemiologic Methods and Concepts*. Birkhaeuser Verlag; Basel: 2004. pp. 1–405

<sup>179</sup> European Commission Joint Research Centre IHCP (2014) *Harmonisation framework for health based evaluation of indoor emissions from construction products in the European Union using the EU-LCI concept*, Report No. 29.

<sup>180</sup> European Commission Joint Research Centre IHCP (2005) *Harmonisation of indoor material emissions labelling systems in the EU*, European Collaborative Action: Urban air, indoor environment and human exposure, Report No. 24.

<sup>181</sup> DIBt, *Draft EU VOC classes*, presentation by Marc Nierhaus, 15<sup>th</sup> January 2016

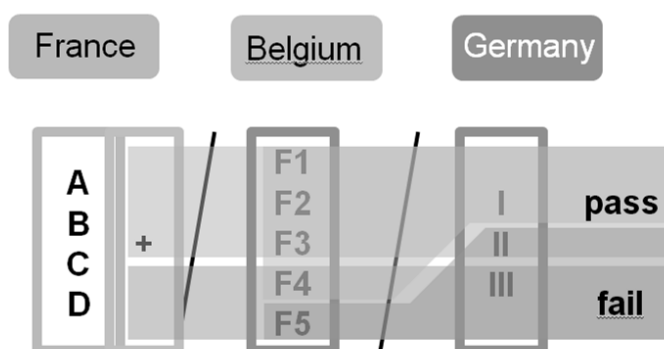


the The reporting will prioritise reporting on Total VOCs (TVOC), formaldehyde, particulates and a number of specific CMR substances with EU LCI values.

Ongoing work, led by DG GROW, to agree a harmonised EU product VOC emissions class system could provide a scope and stable basis for classifying the performance of interior building materials. This initiative has brought together representatives from Germany, France and Belgium.

The final proposal currently looks likely to focus on establishing classes for total VOCs, Carcinogenic VOCs, an R-Value and formaldehyde. This would be a hybrid of the approach adopted by France as a legal labelling requirement for a range of interior products<sup>182</sup>, with the LCI based approach adopted by the German AgBB system. LCI values form the basis for calculating the R-value used in a number of national product emissions schemes, and this aggregated value is currently the subject of discussion for inclusion in the harmonised EU product VOC emissions classes.

Table 6.5 Potential structure of a harmonised EU product VOC emissions class system



Example: **A+ / F3 / I**

Source: DIBt (2016)

### 6.2.5.2 The development of a harmonised building product emissions test method

A harmonised European test method for emissions of volatile organic compounds from construction products into indoor air, CEN/TS 16516, was published in 2013. This established a common method and test conditions based on a 'European reference room' in which products are to be tested.

The technical specification was developed in response to a mandate to address dangerous substances under the Construction Products Regulation. This new test method supercedes the test method EN 717 and chamber test methods specified by ISO 16000 series.

### 6.2.5.3 International recommendations on thresholds for priority emissions

In relation to threshold levels for the emissions specified in the emerging EU class system, ongoing research by JRC-IHCP and WHO guidelines provide a reference point:

<sup>182</sup> Eurofins, France: Compulsory VOC emissions labelling, <http://www.product-testing.eurofins.com/information/compliance-with-law/european-national-legislation/french-regulation-on-voc-emissions.aspx>

- TVOCs: Evidence from JRC-IHCP suggests that concentrations of greater than 1000 mg/m<sup>3</sup> may result in occupants suffering sensory irritation but that levels greater than 25,000 mg/m<sup>3</sup> would be required before significant health effects became a concern <sup>183</sup>.
- Formaldehyde: WHO recommends thresholds of 0.1 mg/m<sup>3</sup> for sensory irritation and 1.25 mg/m<sup>3</sup> for cancer effects <sup>184</sup>.
- Particulates: WHO recommends the following as thresholds <sup>185</sup>:
  - PM2.5: 10 µg/m<sup>3</sup> annual average, 25 µg/m<sup>3</sup> 24-hour mean (no more than 3 days/year)
  - PM10: 20 µg/m<sup>3</sup> annual average, 50 µg/m<sup>3</sup> 24-hour mean

The threshold levels used by three major building assessment schemes for the post-completion testing of indoor air can be seen to be in line with, or stricter, than the thresholds described above.

Harmonised ISO test methods are used for all test specifications, with the exception of the VDI 4300-6 test for VOCs in the German DGNB scheme. The implementation experience with this type of in-situ testing of indoor air quality is further examined in Sections 6.3 and 6.4.

*Table 6.4 Post-completion testing scope and methods for building Indoor Air Quality*

Building scheme	Time frame	Test specification	Test method
LEED (2015)	Post construction, but pre-occupancy.	- Formaldehyde - Particulates (PM10 and 2.5) - Ozone - TVOC - CO - Specific target chemicals	ISO 16000-3 ISO 16000-6 ISO 7708 ISO 4224
BREEAM (2014)	Post construction, but pre-occupancy	- Formaldehyde - TVOC	ISO 16000-3 ISO 16000-6 ISO 16017-2
DGNB (2014)	Maximum 4 weeks post-construction	- Formaldehyde - TVOC	ISO 16000-3 ISO 16000-6 VDI 4300-6

Source: US GBC (2015), BRE Global (2014), DGNB (2015)

#### 6.2.5.4 Linking ventilation rates and indoor air quality

EN 15251 (shortly to be superseded by prEN 16798) proposes indoor comfort classes, ranging from class I to class IV for residential properties, covering thermal comfort, light, acoustics, and IAQ, in which each class is characterized by 'an allowed percentage of dissatisfied occupants'. A building is then assigned a comfort category for each of the listed fields.

Category I is a 'high' comfort level that is recommendable for sensitive or weak persons with special requirements like chronic illness, disability, young children or the elderly; whilst Category II is a 'normal' level recommended for new buildings

<sup>183</sup> European Commission Joint Research Centre IHCP (1997) *Total Volatile Organic Compounds (TVOC's) in indoor air quality investigations*, European Collaborative Action: Urban air, indoor environment and human exposure, Report No. 19.

<sup>184</sup> WHO Europe (2010) *Selected pollutants: Guidelines for indoor air quality*.

<sup>185</sup> WHO Europe (2013) *Health effects of particulate matter*.

and renovations. Category IV is only recommendable for a limited duration of the year. The IAQ-comfort category is determined by the ventilation rate, which is considered as the ability to remove human emissions (CO<sub>2</sub>) as well as emissions from materials used indoors (listed contaminants).

The recommended ventilation rate is determined by a combination of the internal floor area, the expected indoor pollution level and the expected room occupancy. Annex C of EN 15251 and Annex A3 of prEN 16798 define an expected 'low' and 'very low' indoor pollution level. The EN 15251 scope and thresholds for emissions from building materials are presented in Table 6.5. The scope includes emissions of total volatile organic compounds (TVOC), formaldehyde and carcinogenic VOCs, with prEN 16798 extending the scope to include R-Value. Neither EN 15251 or prEN 16798 specify test methods for the pollutants identified.

prEN 16798 is proposed to include a new Annex A6 – WHO health-based criteria for indoor air. This would provide WHO IAQ guideline levels for an expanded list of substances, including benzene, PAHs and particulate matter (PM 2,5 and 10,0). Such a list could be used as the basis post-completion testing and benchmarking.

It is important to note that Annex C in EN 15251 and Annex A6 in prEN 16798 are informative only, having no linked requirements within the associated body of the standards. However, in prEN 16798 Annex A3 is now proposed as being *normative* within the standard.

*Table 6.5 EN 15251 Annex C informative thresholds for low and very low polluting materials*

Pollutant	Emissions from building materials	
	Low polluting thresholds	Very low polluting thresholds
Total Volatile Organic Compounds (TVOC)	< 0,2 mg/m <sup>2</sup> h	< 0,1 mg/m <sup>2</sup> h
Formaldehyde	< 0,05 mg/m <sup>2</sup> h	< 0,02 mg/m <sup>2</sup> h
Ammonia	< 0,03 mg/m <sup>2</sup> h	< 0,01 mg/m <sup>2</sup> h
Carcinogenics (IARC)	< 0,005 mg/m <sup>2</sup> h	< 0,002 mg/m <sup>2</sup> h
Odour emitting materials	Dissatisfaction < 15%	Dissatisfaction < 10%

Source: CEN (2007)

### 6.2.5.5 Ventilation systems and intake air quality

EN standard 13779 specifies design criteria for ventilation systems to maintain indoor air quality, including specifications to apply filtration to the intake of air in areas with poor urban air quality. The standard also includes guidance on the location of ventilation intakes in order to avoid the recirculation of exhaust air.

Poor urban air quality is described in EN 13779 as locations where '*...pollutant concentrations exceed the WHO guidelines or any National air quality standards or regulations for outdoor air by a factor greater than 1,5.*' The Air Quality Directive 2008/50/EC requires Member States to prepare air quality action plans and monitor pollution at a local level. As a result data from air quality monitoring stations shall be made publicly available in each local municipality. This in turn

can, with reference to the standard, enable building designers and developers to make decisions based on knowledge of the quality of outdoor air in locations.

### 6.2.5.6 Building material standards to prevent condensation

ISO 6946 provides a calculation method for the thermal resistance and transmittance of building materials <sup>186</sup>. ISO standard 13788 provides a calculation method for the hygrothermal performance of building components and elements <sup>187</sup>. The standard provides a calculation method for critical surface humidity that may lead to problems such as mould growth on the internal surfaces of buildings, thereby allowing for the assessment of risk.

### 6.2.5.7 Dampness and mould classification system

The Nordic countries have initiated the development of a common standard for the indoor quality of buildings. The draft standard includes a specific category addressing 'dampness and mould in building structures' <sup>188</sup>.

The category introduces a classification of the condition of a building based on expert visual and non-destructive inspection and rating of five criteria (see table 6.6). It is indicated that occurrence and extent of dampness and mould shall be measured in each room and a sum of the areas calculated – although a precise methodology to do this is not specified.

*Table 6.6 Dampness and mould in building structures – proposed Nordic classification system*

Classification criteria	Class 1	Class 2	Class 3	Class 4
Condition of the structures has been checked and the maintenance of structures and installations documented less than 5 years ago:	Yes	Yes		
Known water damages or occurrences of condensation/capillary water have been repaired:	Yes	Yes	Yes	
Visible mould in occupied spaces: - smaller areas (e.g. gasket in a window sash): - minor areas show signs of mould: - larger areas show signs of mould:	None	< 400 cm <sup>2</sup>	< 2.500 cm <sup>2</sup>	> 2.500 cm <sup>2</sup>
Risk of water damages have been assessed and proactive measures taken to reduce the future risk:	Yes			
Moisture from recent construction phase (only for newly constructed buildings):	No	No	Yes	

Source: Danish Standards (2015)

<sup>186</sup> ISO Standards, ISO 6946: *Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.*

<sup>187</sup> ISO Standards, ISO 13788: *Hygrothermal performance of building components and building elements -- Internal surface temperature to avoid critical surface humidity and interstitial condensation -- Calculation methods.*

<sup>188</sup> Draft standard communicated by Danish Standards and Nordic Innovation

## 6.3 Findings from investigation of the selected field study clusters

The macro-objective 1 field studies consist of four clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- ALTO Office projects – new-build and renovation (France and Luxembourg): Certification criteria;
- OFFICEAIR: Pan-EU monitoring of influences on office air quality;
- Clean air, low energy: Specification and monitoring of new-build projects;
- Renovair: Specification and monitoring of housing renovation projects.

For each cluster, the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

### 6.3.1 Cluster 1: ALTO office projects – new-build and renovation

#### 6.3.1.1 Background and context to selection of the cluster

*An overview of this ALTO building cluster is provided in Section 2.4.*

#### 6.3.1.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The following areas of focus for improvement were identified in relation to the projects. They are related in each case to the distinct requirements of each assessment scheme.

##### 6.3.1.2.1 Hazardous substances – ventilation intake

Minimum flowrates of the ventilation are required for the office spaces. Different threshold values are used, depending on the certification scheme. They are normalized per occupant. Reference standards are: EN 13779 and EN 15251 for HQE and BREEAM / ASHRAE standard 62.1-2007 for LEED. Flow rates have to be calculated taking into account the pollution of the outdoor air outside the building and pollution in the building linked to material emissions.

*Table 6.7 Certification scheme ventilation requirements applying to the office buildings*

Scheme criteria	Performance requirements	Buildings
<b>HQE 11.1/13.1:</b> ensuring an efficient ventilation	25 m <sup>3</sup> /h/per in offices spaces (French regulation) as a minimum (base performance level). Higher performance levels have corresponding flow rates.	ALL
<b>BREEAM HEA 8:</b> Indoor Air quality	36 m <sup>3</sup> /h/per in offices spaces	ZENORA CBKII EULER
<b>LEED IEQp1-IEQc2</b> minimum Indoor Air Quality Performance Increased Ventilation	Design Outdoor Air Intake flow have to achieved LEED specific recommendations. It must be calculated for each project and the result is given in ft <sup>3</sup> /min/per	LA MARSEILLAISE
<b>LEED IEQc5</b> Indoor Chemical and Pollutant Source Control	Design to minimize and control the entry of pollutants into buildings and later cross-contamination of regularly occupied areas	LA MARSEILLAISE

### 6.3.1.2.2 Hazardous substances – material emissions

DGNB: Indoor TVOC concentrations for DGNB’s scheme are determined based on the relevant standards (EN ISO 16000-6, SO 16000-3). The TVOC content of indoor air must be determined by chemical analysis no more than four weeks after building completion and before furniture is installed.

The minimum number of rooms to be tested is specified in the following table. The chemical compounds to be tested for include all of those which fall under the German Building Product Testing and Evaluation Scheme developed by the German Committee for Health-related Evaluation of Building Products (AgBB). In addition, concentrations of formaldehyde in the indoor air are tested.

HQE, BREEAM, LEED: materials in contact with indoor air have to comply with specific requirements and the surface depends on the certification scheme and performance to achieve (50% as minimum for HQE and 100% for BREEAM and DGNB).

Table 6.8 Certification scheme product requirements applying to the office buildings

Scheme criteria	Performance requirements	Buildings
<b>HQE 2.4/13.2</b> : choosing building components to limit the sanitary impact of the construction/control of internal pollution level	Assess VOC and formaldehyde emissions for 100% of the surface in contact with indoor air (occupied spaces)	ALL
<b>BREEAM HEA 9:</b> Volatile organic Compounds	criteria for paintings, wood panels, timber structures, wood flooring, resilient textile and laminated floor coverings, suspended ceiling tiles, flooring adhesives, and wall covering for 100% of the surface in contact with indoor air (occupied spaces)	ZENORA CBKII EULER
<b>DGNB Criterion 20:</b> Indoor Air quality	category III of annex B of EN 15251	CBKII
<b>DGNB Criterion 6:</b> Local environmental impact	Respect of all DGNB criteria, 100% of level 2  (Avoided or reduced risks to human health by substituting materials with less harmful equivalents. A qualitative evaluation of the materials specified is therefore required to ensure that the materials specified represent a lower risk.)	CBKII
<b>LEED IEQc4.1 to 4.4</b> Low emitting materials	All adhesives and sealants, paints and coating, flooring, ceiling walls and thermal + acoustic insulation and composite wood used on the interior of the building (i.e., inside of the weatherproofing system and applied on-site), must comply with LEED requirements	LA MARSEILLAISE

Requirements of HQE: are according to European directive 2004/42/CE. A French regulation was published on 25 March 2011 regarding a mandatory labelling of construction products installed indoors, floor and wall coverings, paints and lacquers with their emission classes based on emission testing. This regulation foresees that since 1. Jan. 2012, any covered product placed on the market has to be labelled with emission classes based on their emissions after 28 days, as tested with ISO 16000 and calculated for European reference room.

### 6.3.1.3 How performance improvements were measured

*Potential indicators identified:*

- Ventilation flow rate (m<sup>3</sup>/hr/per)
- VOCs emission (%)
- Filtration classes of polluted external air

*Supporting indicators:*

- Temperature
- Indoor CO<sub>2</sub> (CO<sub>2</sub>-sensors for spaces with unpredictable or variable occupancy patterns)

The measurement of mould has also been carried out in order to provide evidence of the sanitary quality of building, but this is not linked to a certification requirement. The reference standard is AFNOR XP X 43-401 and the unit of measurement is Colony Forming Units (CFC)/m<sup>3</sup>. No local regulation or guide to compare derived values is understood to exist, but the specialist employed to carry out the analysis has compared them to those from other refurbished offices.

### 6.3.1.4 Implementation experience of practitioners involved with delivery of the improvements

Calculations are updated along the design process and construction works. This is the certification's requirement to achieve the credits. The engineers are responsible for the installation but they are also responsible for the follow-up during construction (and the update of calculations when necessary). Feedback from as built projects indicate that results of flow rate measurements are not always easy to acquire from the contractors.

Certification to BREEAM (2009 scheme) required a test certificate for each product supervised by European testing methodology. All the projects had difficulties in particular with flooring adhesives and paints and varnishes that were used in internal spaces instead of their intended use for external spaces (but classified for the two uses by manufacturers). This is because they prove to result in higher VOC emissions than allowed for internal spaces although they comply with the Decopaint Directive thanks to their double classification.

HQE's aim is understood to be the encouragement of the provision of environmental data more than achieving consistency in the values. Test certificates are not required and VOC performance is often linked to a label or manufacturers data.

Please note that at the present time, BRE accepts eco labels for products which does not always mean that a test carried out according to European methods has been used. Concerning the trade-off between energy performance and indoor air quality, clients tend to prioritise energy performance more than health and comfort. As a result, for projects with a low general score under BREEAM, and in order to achieve the necessary credits, energy tends to be prioritised over IAQ efforts.

Post-completion measurements were conducted in the EULER building, one month after completion but before occupation. The results are still good on average but it can be highlighted that despite a high filtration class, excellent ventilation flow rates and the choice of low VOC emission materials, the indoor quality is still disappointing in some spaces, with limit values being exceeded for benzene and xylene. This seems to be the case in spaces where windows are often opened and polluted outdoor air from Paris's city center entered the building as a result. Furthermore, the measurements conditions were not ideal: carpets as well as crawlspaces and ventilation channels were not cleaned well, windows were

opened with the result that external pollution entered in the building before the ventilation's commissioning.

Measurements have not been conducted yet for CBKII.

Draft document



## 6.3.2 Cluster 2: OFFICAIR

### 6.3.2.1 Background and context to selection of the cluster

Officair<sup>189</sup> is a European project funded by the FP7 programme for the call ENV.2010.1.2.2-1 - Indoor air pollution and health risks of modern office buildings. Fifteen partners from ten countries (Belgium, Netherlands, France, United Kingdom, Denmark, Spain, Italy, Greece, Portugal, Hungary) were involved, and also including the University of Western Macedonia (coordinator) and VITO

The main aim of the OFFICAIR project was the assessment and evaluation of the indoor air quality (IAQ) and health effects in European office buildings. The field study analysis mainly focusses on the results of the assessment and evaluation framework, which included an IAQ assessment in Southern, Central and Northern Europe; optimization of IAQ and exposure modelling; and the evaluation of health effects and health risks.

Table 6.9 OFFICAIR field study locations and buildings

Building	Climate zone, Location	Typology	Type	Scale	Stage
16 Office buildings	Southern Europe: Spain, Greece, Italy and Portugal	Offices: low-rise, medium-rise, high-rise	New-build and renovated, all existing ('modern offices')	Up to 5 stories; 4 units in each building	in use
13 Office buildings	Central-Europe: France, the Netherlands	Offices: low-rise, medium-rise, high-rise	New-build and renovated, all existing ('modern offices')	Up to 5 stories; 4 units in each building	In use
3 Office buildings	Northern Europe: Finland	Offices: low-rise, medium-rise, high-rise	New-build and renovated, all existing ('modern offices')	Up to 5 stories; 4 units in each building	In use
5 Office buildings	Eastern Europe	Offices: low-rise, medium-rise, high-rise	New-build and renovated, all existing ('modern offices')	Up to 5 stories; 4 units in each building	In use

### 6.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

Officair focussed on exposure of hazardous substances, either from ventilation intake air or from materials emissions. The IAQ of offices was assessed via a measurement campaign on European scale. The measurement campaign consisted of three complementary phases: a "general survey" based on questionnaires (167 buildings); a "detailed study" with measurements carried out both in summer and in winter (32 buildings); and an "intervention study" with deeper measurements (e.g. active sampling and on-line monitoring) carried out before and after an intervention related to IAQ (9 buildings). The indoor air monitoring was carried out before and after four weeks of use, and at two locations: the intervention room and the control room.

<sup>189</sup> Officair (2013) *Officair* [online] <http://www.officair-project.eu/> [20/5/2016]

The measurement methods applied are illustrated in the case of Greece (Sakellaris et al., 2013)<sup>190</sup>:

*“measurements were conducted in five modern office buildings located in urban and suburban area of Athens. Specifically, in each building, sampling took place at four indoor (office rooms) and one outdoor site. Each sampling period lasted for five weekdays (Monday to Friday). In particular, measurements included passive sampling of VOC (Volatile Organic Compounds), Aldehydes, O<sub>3</sub> and NO<sub>2</sub>.*

*Additionally, PM<sub>2.5</sub> samples were collected with low volume samplers on quartz fiber filters. Physical parameters (temperature, relative humidity, visible and UVA radiation, wind speed, ultra-fine particles) were also monitored. Finally, ventilation was estimated by the passive PerFluorocarbon Tracer (PFT) technique as well as the mechanical flow rate was measured actively using flow meters.”*

The intervention study also included emission testing of materials typically present in modern office rooms (flooring, desks, computer screens, printers, office chairs, simulation of cleaning activities).

### **6.3.2.3 How performance improvements were measured**

*Key indicators:*

- VOCs, TVOC, aldehydes [ $\mu\text{g}/\text{m}^{-3}$ ]
- particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>) [ $\mu\text{g}/\text{m}^{-3}$ ]
- O<sub>3</sub> [ $\mu\text{g}/\text{m}^{-3}$ ]
- NO<sub>2</sub> [ $\mu\text{g}/\text{m}^{-3}$ ]
- Indoor/outdoor (I/O) ratios of pollutants
- Flow rate [l/s/per; l/s/m<sup>2</sup>; m<sup>3</sup>/h]
- Air Change rate per hour (ACH) [h<sup>-1</sup>]

*Supporting indicators*

- Temperature [°C]
- Relative Humidity [RH]

A comparison with the existing IAQ guidelines (e.g. from the World Health Organization) showed that indoor concentrations in office buildings could exceed the reference values for *benzene* and *PM<sub>2.5</sub>*.

IAQ measurements were performed in Winter and in Summer. Results were compared to each other, and findings indicated that higher indoor concentrations were observed in winter for *benzene*, *limonene*,  *$\alpha$ -pinene* and *nitrogen dioxide*. Conversely higher indoor concentrations were observed in summer for *formaldehyde* and *ozone*. This indicated that a one week sampling strategy is not enough to approach a “long term” concentration.

In addition to this temporal or seasonal variability, the in-situ measurements indicated a spatial variability (for instance, higher concentration of outdoor pollutants in the indoor air of office spaces on ground floor versus office spaces on higher level) and an indoor/outdoor relationship (for instance, high Input/Output ratios for selected VOCs and aldehydes indicate that these are more prominent in the indoor air, while low Input/Output ratios for O<sub>3</sub> and NO<sub>2</sub> indicate the contrary).

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<sup>190</sup> I.A. Sakellaris, D.E. Saraga, K.K. Kalimeri, E.M. Kougioumtzidis, V.G. Mihucz, R. Mabilia and J.G. Bartzis (2013) *Air Quality measurements in indoor environment of modern offices in Athens, Greece (Officair Project)*

#### **6.3.2.4 Implementation experience of practitioners involved with delivery of the improvements**

Officair formulated three key recommendations for an improved IAQ. These key recommendations are in-line with the findings of the EnVIE<sup>191</sup> and HealthVent initiatives and follow the precautionary principle that prevention is better than remediation. This is translated as follows: the first two recommendations focus on 'source control', the third focusses on 'exposure control'.

##### *1st recommendation: Limit entrance of pollutants from outdoor*

A clean outdoor air quality is a prerequisite. This does not only relate to regionally high outdoor pollutant levels, but can also relate to local sources, for instance motor vehicle exhaust from nearby roadways. When this is not the case, ventilation air should be treated, by being filtered or even washed. Otherwise outdoor becomes a pollution source indoors. In the case of pre-construction and building design phase, the building location should be treated as a first component of the source control strategy.

##### *2nd recommendation: Limit pollutants from indoor sources by choosing low emission cleaning products, building materials and furniture*

This recommendation does not only relate to the building project team, who can choose low emitting tested and approved materials and products, but also addresses the policy level: policy can lead manufacturers to decrease the pollutants that are emitted from the construction, furniture and cleaning products.

The results of the Officair field studies highlighted also a very important issue: IAQ assessment techniques focus on assessment of individual indoor air compounds, but in reality, indoor air compounds chemically react with each other. One possible way to assess the real impact of cleaning products as well building materials, would be emission testing in natural conditions, rather than in artificial clean air conditions. In addition, elimination or reduction of the main reactants would be possible by advanced labelling systems on which designers can base material selection.

Another factor that has to be taken into account, is the fact that emission rates vary significantly over time: for a given product, emissions of some chemicals decay rapidly (within hours or days), while others as carpet and vinyl tiles may release pollutants less volatile at nearly constant rates for many months. The acute or long-term impacts of materials can thus be dramatically different and need to be factored into product assessment.

Finally, in the evaluation of emissions impacts, materials need to be considered as parts of systems whenever possible. For instance, carpeting is not independent of cushions, adhesives or subfloors. Emissions from a system may be markedly different than those from its individual constituents.

##### *3rd recommendation: Limit exposure by using a ventilation strategy based on health criteria*

The use of ventilation should be understood as an „exposure control“ tool after source control measures have been adopted. It should be based on health criteria instead of relying heavily on comfort criteria. Bearing in mind the meaning of „exposure“, there are ways of limiting it by other means that do not imply changing the ventilation rate, for instance, the ventilation rate can be variable along the occupational period, according to the scheduled activities.

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<sup>191</sup> EnVIE (2009) *Objectives and approach of EnVIE* [online], available at: <http://paginas.fe.up.pt/~envie/> [20/5/2016]

### **6.3.3 Cluster 3: Clean air, low energy**

#### **6.3.3.1 Background and context to selection of the cluster**

The aim of the exploratory study "Clean air, low energy" was to assess the indoor air quality (IAQ) in energy-efficient and passive buildings, including homes and schools<sup>192</sup>. Physical, chemical and biological parameters have been measured in order to determine whether indoor air in such buildings differs from non-energy-efficient buildings.

A particular focus was put on how the outdoor environment, building air-tightness and ventilation systems affect indoor parameters. In total 51 indoor (and respective outdoor ) sites in low-energy buildings, equipped with a mechanical ventilation system (controlled supply and exhaust air as well as trickle ventilators with controlled exhaust air) in Flanders (Belgium) were studied (of which 25 houses and 26 classrooms).

The 25 Clean Air Low Energy residences were built in Flanders between 2008 and 2011. 15 residences are detached houses, 5 semi-detached, 2 are terraced houses, and one of the buildings consists of three apartments. Six residences are build with a lightweight wood frame structure, the others have a more common brick or concrete structure.

#### **6.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

Clean air, low energy is a post-occupation evaluation study. While the comparison of different performance improvements options were not a specific part of the research, the measurements performed in the study do provide insight on the relation between the IAQ on the one hand and building characteristics on the other hand. More particular, the study indicates to which extent the choice and design of the ventilation system and the performance of the building envelope regarding airtightness could influence the IAQ.

Monitoring data was collected using diffusive passive samplers to monitor TVOC, VOC and aldehydes; air samplers to monitor particulate matter; measurement units to record CO<sub>2</sub>, Relative Humidity (RH) and temperature; pressurization tests to measure the airtightness; and samplers for biological parameters (fungi, yeast, bacteria). The user satisfaction concerning the indoor environment, the thermal comfort and noise nuisance was assessed via questionnaires.

#### **6.3.3.3 How performance improvements were measured**

*Key indicators:*

- Indoor air pollutant concentrations (VOCs, TVOCs, aldehydes, particulate matter PM<sub>2.5</sub>, PM<sub>10,0</sub>) [ $\mu\text{g}/\text{m}^3$ ]
- Flow rate [ $\text{m}^3/\text{h}$ ]
- Air Change Rate or Air Changes per Hour (ACH) [ $\text{m}^3/\text{m}^3/\text{hr}$  @50Pa]
- Airtightness n50 [ $\text{m}^3/\text{m}^3/\text{hr}$  @50Pa]
- Concentration of biological agents (fungi, yeast and total bacteria) [Colony Forming Units (CFU)/ $\text{m}^3$ ]

*Supporting indicators:*

- Temperature [K]
- Relative Humidity (RH) [%]
- Indoor CO<sub>2</sub> concentration [ppm]

Regarding hazardous substances, of all identified VOCs in Clean Air Low Energy, formaldehyde, d-limonene,  $\alpha$ -pinene, and toluene were most abundant in indoor air. Regarding biological agents, the average levels of total viable fungi indoors

<sup>192</sup> Clean Air, Low Energy (2012), <https://esites.vito.be/sites/cleanairlowenergy/EN/home/Pages/home.aspx>

were comparable or slightly lower compared to the outdoor average concentrations ( $1.5 \times 10^2$  and  $4.2 \times 10^2$  CFU/m<sup>3</sup>, respectively).

Regarding flow rate and air change rates, the measurement results as illustrated in Figure 6.6 and 6.7 show that the occupants operated their ventilation system at a much lower rate (median=0.24 ACH, average=0.24 ACH) than the design flow rate specified in the Belgian residential ventilation standard<sup>193</sup> (about 1 ACH).

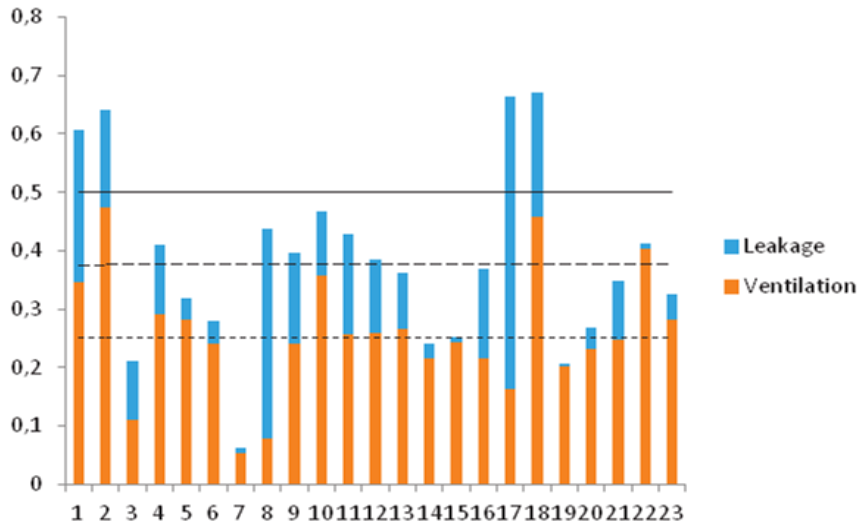


Figure 6.6: Total air change rate (ACH) in the residences, subdivided by leakage and ventilation

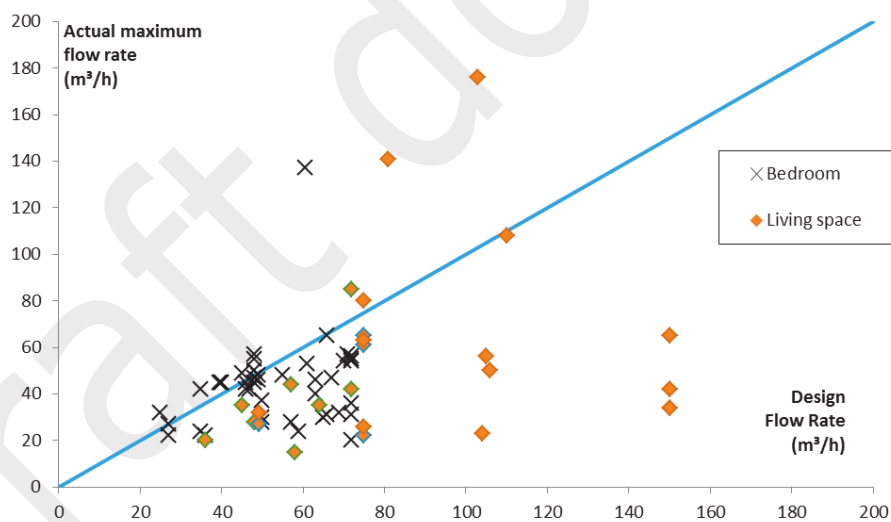


Figure 6.7: Actual maximum mechanical flow rate and design flow rate for all living spaces and bedrooms in the residences with heat recovery ventilation

Source: Clean Air, Low Energy (2012)

To investigate the relation between airtightness and the indoor air quality, three airtightness classes were identified for the residences:

<sup>193</sup> BIN, Ventilatievoorzieningen in woongebouwen, in, Brussels, 1991

- Airtightness group 1:  $n_{50} \leq 0.6$  (very airtight)
- Airtightness group 2:  $0.6 < n_{50} \leq 2.5$  (airtight)
- Airtightness group 3:  $2.5 < n_{50}$  (moderately airtight)

The airtightness criterion  $n_{50}$  is derived from the Passivhaus standard. It is the proportion of the buildings internal volume of air that is changed per hour at 50 pascals of air pressure *i.e.* 0.6 would equate to 60% of the internal volume.

One of the main findings was the fact that more airtight residences were characterized by a lower air change rate. However, the residential indoor  $\text{CO}_2$  level appeared to be independent of the airtightness. This finding indicates that a high building airtightness does not necessarily prevent an effective building aeration.

The presence of all chemical compounds monitored, as well as temperature and relative humidity, appeared to be independent of the level of airtightness of residences. No clear trends could be identified for viable fungi and bacteria in residential indoor air in buildings of different levels of airtightness. A classification of the dwellings in relation to a minimal total air change rate of 0.5 ACH was used.

In general, it can be concluded that a lower ACH class (higher total air change rate) in residences does not imply distinct differences between the occurrence of chemical components in the living rooms. There is only an indication of a minor improvement for TVOC, formaldehyde and  $\text{CO}_2$  in the lowest ACH class, compared to the other classes. Viable fungi and bacteria however, seemed again to increase in lower ACH classes.

However, following conditions should be taken into account:

- Residences are characterised by a much wider variety of different indoor sources (such as cooking, household products, furniture, etc...) than other building typologies, for instance schools.
- The residences are categorized in 4 classes, not taking into account the amount of occupants (since this is variable from day-to-day and within one day).
- Total air change rate and the airtightness are monitored and calculated at building level. The IAQ of residences is determined in the living room.

#### **6.3.3.4 Implementation experience of practitioners involved with delivery of the improvements**

The IAQ in energy-efficient, mechanically ventilated houses and schools was found to be moderately improved or equal to the IAQ monitored in traditional buildings. There is no indication that the trend towards energy efficient buildings will cause detrimental effects on IAQ and human health.

In energy-efficient, mechanically ventilated buildings (trickle ventilators with controlled exhaust as well as controlled supply and exhaust air),, most chemical compounds occur at similar or somewhat lower concentration levels compared to traditional buildings. Mechanically ventilated buildings are clearly more effectively ventilated than traditional buildings. This finding indicates that sufficiently ventilated buildings could be characterised by even more reduced indoor concentration levels if an efficient source reduction strategy would be implied. More guidance on the usage of low-emitting building materials and consumer products; labelling of products, or regulations on material emissions would be of considerable value to achieve this goal.

Greater awareness and information on use and maintenance of the ventilation system is needed (generally the ventilation system is used at a low set point),

since most of the users do not seem to be aware of the impact or functionality of their ventilation system. Quality assurance for ventilation systems would imply an added value to the quality of the indoor environment: commissioning is necessary since this study, in accordance with others, demonstrates that the design flow rates specified in the standards are not met in a majority of cases.

There is a lack of baseline information of viable fungi and bacteria in Belgium, Flanders, in complaint-free, traditional houses and schools. Also the interrelation between chemical/physical/biological characteristics and their behaviour in traditional, in newly built and in renovated buildings should be studied more in detail.

### 6.3.4 Cluster 4: Renovair

#### 6.3.4.1 Background and context to selection of the cluster

Renovair is a pilot study in the Flemish region (Belgium). In total, 16 renovated residences were studied, of which 11 were investigated before and after the renovation. The other 5 renovation projects were only studied after the renovation activity took place. As a result, 27 measurement entities in total are included in this study.

The purpose was to generate representative data for Flanders on indoor environments pre and post energy-efficient renovations, in order to explore the impact of specific renovations on the indoor environment. The Renovair study is a follow-up of the Clean Air Low Energy study. The research questions, methodology and results are therefore closely related.

The study does not only focus on the relationship between indoor air quality and overall energy performance of the building, but also the relationship between indoor air quality and individual (or a combination of) renovation measures.

Table 6.10 Description of the studied buildings (source: Renovair)

nr	Renovation activity	Construction date	Environment	Type	Construction
1	Upgrade windows – case 1	1991	rural	detached	bricks
2	Upgrade windows – case 2	1987	rural	detached	bricks
3	Floor insulation – case 1	1963	urban	terraced	bricks
4	Floor insulation – case 2	1952	urban	detached	bricks
5	Rising damp – case 1	1967	rural	detached	bricks
6	Rising damp – case 2	1925	urban	semi-detached	bricks
7	Combi/thorough – case 1	1972	urban	semi-detached	bricks
8	Combi/thorough – case 2	1933	rural	detached	bricks
9	Combi/thorough – case 3	1952	urban	detached	bricks
10	Combi/thorough – case 4	1850	urban	semi-detached	bricks
11	Combi/thorough – case 5	1960	urban	terraced	bricks
12	Mechanical ventilation – case 1	1959	rural	detached	bricks

13	Mechanical ventilation – case 2	1969	rural	detached	wood
14	Duct cleaning – case 1				
15	Duct cleaning – case 2				
16	Façade insulation – case 1	1959	rural	detached	bricks

#### 6.3.4.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The renovation measures selected for Renovair, are representative energy-efficient measures in the Flemish building stock. The studied renovations include: window upgrades, floor insulation, wall treatments against rising damp, the installation of a mechanical ventilation system, façade insulations, air filter replacements as well as initiatives of more thorough energy-efficient renovations, which consist of several of the individual renovation initiatives.

For each renovation type, at least two cases (i.e. two buildings) were studied. The assessment carried out was similar to the assessment in Clean Air, Low Energy and included an assessment of conditions indoors as well as outdoors, a study of the microbial content of settled dust, an assessment of air tightness and ventilation rates, and a thorough survey on indoor well-being and comfort of building occupants. Renovair also included a study of surface temperatures using thermographic scans.

Post renovation assessments took place only six months after the renovations. In case a risk for a considerable or a specific emission from used building materials was assumed, a dedicated IAQ assessment was organised within one week after the renovation.

Finally, Renovair specifically investigated the extent to which home owners or architects want to achieve a healthy IAQ by choosing low-emission building materials. Besides the applicable EU regulations, Belgium has only limited regulations that restrict building material emissions, and has no mandatory product label that applies for all building products that are available on the Belgian market.

#### 6.3.4.3 How performance improvements were measured

*Key indicators identified:*

- indoor/outdoor ratios of indoor air pollutants (I/O-ratio): PM<sub>2.5</sub>, CO<sub>2</sub>, TVOC, aldehydes
- other indicators: see Clean Air, Low Energy

*General evaluation of the impact of renovations on indoor environmental parameters*

Indoor aldehydes (formaldehyde, acetaldehydes and to a lesser extent the sum parameter other aldehydes) were found at increased indoor levels more than six months after the renovation activity took place. This finding indicates that more than 6 months after the renovation activity took place, certain emissions originating from the indoor use of building materials may still be present indoors.

The selection of low VOC emitting building materials lead to a direct improvement of the IAQ in terms of indoor TVOC and formaldehyde, according to a small qualitative study of four of the Renovair cases.



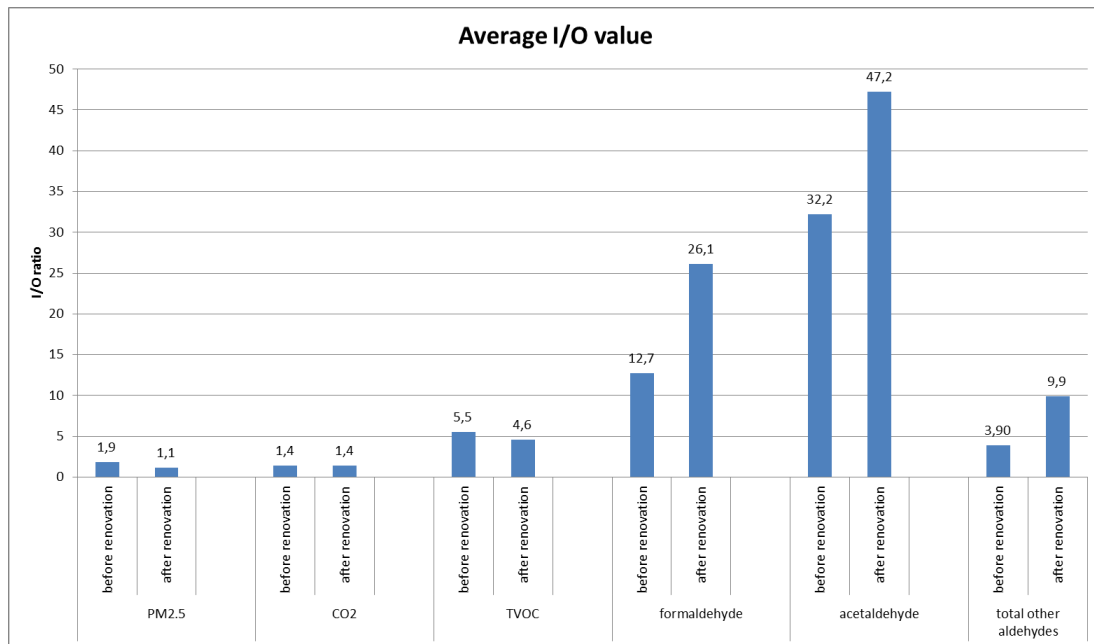


Figure 6.8 Indoor/Outdoor ratios (I/O-ratio) prior to and 6 months after the renovations for selected hazardous substances (source: Renovair)

#### Evaluation of the effectiveness and impact of specific renovations on the indoor environment

For most of the studied cases, a relation between IAQ and ventilation characteristics (air tightness and ventilation rate) can be noticed in the Renovair dataset.

- Outdoor levels of volatile organic compounds (VOCs) and PM<sub>2.5</sub> are reflected in the corresponding indoor concentration.
- The installation of more insulated windows did not affect the IAQ, or the building air tightness, and a ventilation system type A (natural ventilation) did not lead to reduced indoor CO<sub>2</sub> levels compared to a non-mechanically (naturally) ventilated house.
- The installation of floor insulation led to increased TVOC and formaldehyde levels post renovation, but also raised the floor temperature with 3°C. Within a week after installing the PUR floor insulations, traces of dimethylbenzylamine, a catalyst for foam formation, were detected in the living room.
- Wall treatment against rising damp was found to affect indoor VOCs (increased TVOC level, traces of epoxy silanes) at differing levels less than a week after the installation and was found at reduced indoor levels again 6 months after the installation.

In one house, TVOC concentration levels reached a level that is ranked according to the German Indoor Air Quality guide values as '*should not be exceeded in rooms for long-term residence*' (1-3 mg/m<sup>3</sup>). Six months after the renovation the concentration levels had decreased to levels classified by the same institution as '*ideal conditions*'.

Only in one of the two studied cases, moisture in walls was found to decrease. It was found in some cases that some cold spots present before the renovation, were still present after the thorough renovation and that unfinished renovations (finishing works) also affected the air tightness of the building.

#### **6.3.4.4 Implementation experience of practitioners involved with delivery of the improvements**

According to the Renovair data, cold bridges present before the renovation are in some cases found to be more pronounced post renovation. The air tightness around the joinery in the façades was a point of particular interest in the thorough renovation cases. Older front doors and garages clearly showed heat losses around the frames.

The awareness for this phenomenon could be raised (e.g. by incorporating it in subsidies, or by mandatory follow-up of renovation planning by an expert). A similar finding was reported in the Finland 'Moisture and Mould programme'. In a new Decree (REF) set by the Social Affairs and Health Ministry in Finland, the government offers the possibility for a professional house inspection (person with qualifications according to requirements set by the government) in houses with health hazards, who formulates recommendations for a suitable renovation of the private dwelling.

Thorough initiatives for selecting low VOC emission materials lead to a direct improvement of the IAQ in terms of indoor TVOC and formaldehyde. There is a need for guidelines and tools for building professionals and citizens for selecting low VOC-emitting building materials. The table for building material selection in the guide 'Bouw Gezond' for building professionals, is a very useful tool in this context<sup>194</sup>.

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<sup>194</sup> Environment, Nature and Energy Department (2016) *Fiches Bouw Gezond (Dutch)* [online], available at <http://www.lne.be/campagnes/bouw-gezond/bouw-gezond/meer-informatie/fiches-map-bouw-gezond/fiches-bouw-gezond> [20/5/2016]

## **6.4 Findings from the operational experience of selected assessment and reporting schemes**

### **6.4.1 Assessment and reporting schemes**

In this section, a summary of the main themes and findings to have emerged from a detailed cross-check of relevant criteria from five certification schemes – BREEAM UK, HQE, DGNB, LEED and VERDE (based on SB Tool) - together with associated interviews are presented.

Reference is also made to the criteria of a number of residential-only schemes – Home Performance Index (Ireland), Home Quality Mark (UK), Klimaaktiv (Austria) and Miljo Byggnad (Sweden).

The main observations are grouped into common themes that emerged from the research.

#### **6.4.1.1 Product selection to reduce emissions**

The availability of products that have been tested according to standardised test methods and for which verified performance data could be obtained was generally seen as good. A variety of mandatory and voluntary product emissions schemes provide readily available performance data that support verification.

The process of selecting products is in general considered to be relatively easy for applicants because it is simply a case of specifying according to the product listings provided. The market in certain EU countries was considered to have matured since the introduction of such criteria, and this process is now much easier. In some countries, many products now provide a high performance or achieve high ratings because the market has moved to provide improved product performance.

However, it should also be recognised that, in some countries, the market is less mature, making product selection more difficult. Where criteria have no reference point in national legislation, this can result in a low take up of requirements.

In some countries such as Germany, the scheme criteria are very comprehensive in the scope of products for which performance data shall be obtained. This is considered to be important because otherwise there is the risk that upon testing the actual indoor air quality result will be poor.

#### **6.4.1.2 The relationship between indoor emissions and ventilation systems**

Stipulated ventilation rates vary across the EU. In countries where rates are in general lower, either due to regulation or building practices, this can make it difficult to comply with standards such as EN 15251.

Purges of interior air prior to occupation are carried out, usually as part of the building commissioning process. However, it is a difficult process to verify, with the cost of having assessors on site cited as a significant barrier.

#### **6.4.1.3 Post-completion testing**

In general, although there is increasing interest, post-completion testing is still rarely carried out. With one exception being Germany where, because of the importance of indoor air quality in the market, DGNB and BNB have made testing compulsory for all certifications. This also encourages a link to be made between the selection of building materials and the test result.

With the exception of the previously cited example, there appear to be few actual examples of buildings for which post-completion air quality results can be obtained for comparative purposes. Reasons cited included complexity, cost and

the availability of specialists and mobile equipment – although in some countries such as Germany market demand has meant that there is good availability. A further issue is timing – the 'window of opportunity' between completion and occupation can be restrictive.

The difference between carrying out testing post-completion (i.e. before occupation) and upon occupation was highlighted. The latter is a sensitive issue in some EU countries because the results can be very high due to the influence of items such as furniture. This can give reason for Unions and employees to take action against employees. Building owners and large companies are therefore reluctant to carry out testing during occupation. It is also difficult to identify a cause and effect relationship between the results and different materials and objects within the building.

In some countries such as Germany where post-completion testing has become more common, it is claimed that it is now well understood by both clients and tenants, moreover, it is actually requested because it is used as a mark of quality.

The Irish HPI and UK HQM residential schemes will introduce such testing as optional credits. In the case of Ireland with a more limited scope that specifies only testing for formaldehyde. The UK will also reward testing for total VOCs.

## **6.4.2 Progress made by scheme harmonisation initiatives**

### **6.4.2.1 Common Metrics pilot phase 1, Sustainable Building Alliance**

The Sustainable Building Alliance's initial set of indicators (the 'Common Metrics') included one indicator relevant to macro-objective 4a – formaldehyde concentration. The indicator is specified with the option for assessment at a number of stages:

- Before use stage: Choice of low emitting materials as part of the design, measured in  $\mu\text{g}/\text{m}^2$ ;
- Post construction stage: Measurement post-completion but before occupation of indoor concentrations in  $\mu\text{g}/\text{m}^2$ ;
- During the use stage: Measurement during occupation of indoor concentrations in  $\mu\text{g}/\text{m}^2$  with furniture, fixtures and fittings in place;

Measurements shall be taken in representative rooms e.g. 10% of apartments or offices. Product testing shall be with reference to EN 717-1 (now superseded by CEN/TS 16516). Indoor measurements shall be with reference to ISO 16000-3.

It is noted that in future revisions of the common metrics, other dangerous substances may be added.

### **6.4.2.2 Common European Sustainable Building Assessment (New public buildings v1.1), CESBA**

Whilst the indicator catalogue does not contain a specific indicator that addresses chemical or biological emissions, reference is made to the Austrian klima:aktiv haus indicator catalogue. This includes requirements for interior products, including flooring, associated adhesives, insulating materials and wood-based materials. Reference is made to emissions of VOCs, SVOCs and formaldehyde.

## 6.5 Identification and screening of potential performance indicators

### 6.5.1 Long list of macro-objective 4a direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope			Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage	Building aspects			
<b>4.1 Hazardous substances – ventilation intake</b>							
<b>Air Change Rate or Air Changes per Hour</b>	m <sup>3</sup> /m <sup>3</sup> /hr	B1-7: Use	Design stage In-use	Air leakage Ventilation	EN 13829	-	FS
<b>Airtightness</b>	n50 [m <sup>3</sup> /m <sup>3</sup> /hr]	B1-7: Use	In-use	Air leakage Ventilation		-	FS
<b>Flow rate</b>	m <sup>3</sup> /hr	B1-7: Use	Design stage	Ventilation	EN 13779	-	FS
			In use		Flow rate measurements		FS
<b>Supply indoor air quality rating</b>	IDA classes	B1-7: Use	Design stage In-use	Ventilation	EN 15251 EN 13779	-	FS
<b>Filtration classes of polluted external air</b>	Filter classes	B1-7: Use	In-use	Ventilation	EN 13779	Link to WHO classification of external pollution	FS
<b>I/O ratio (indoor/outdoor ratio of pollutant concentrations)</b>	[dimensionless]	B1-7: Use	In-use	Ventilation	EN 13779	VOCs, TVOCs, aldehydes, particulate matter (PM <sub>2.5</sub> , PM <sub>x</sub> , PM <sub>10</sub> ), CO <sub>2</sub>	FS

4.2 Hazardous substances – source control							
<b>Indoor air pollutant concentrations</b>	$\mu\text{g.m}^{-3}$	A1-3: Production A4-5: Construction B1-7: Use	Concept design Technical design In-use	selected building materials and finishes	EN 16798 (WHO guidelines) Proposed EU emissions class scheme	indoor air pollutants related to material emissions: VOCs, TVOCs, aldehydes	FS AR
		B1-7: Use	Handover and close-out In-use	In situ air quality		pollutants from the outside air that can enter the building either at the intake or within the building: particulate matter PM2.5, PM10,0	FS AR
<b>Rating or classification system for building materials</b>	Emissions class, R Value and/or $\mu\text{g.m}^{-3}$	A1-3: Production A4-5: Construction B1-7: Use	Concept design Technical design Construction Refurbishment	Internal fit out and finishing materials (variable scope)	Schemes and databases in selected Member States (e.g. AGOV, Germany) BASTA <sup>195</sup> , SUNDAHUS <sup>196</sup> (Sweden))	-	FS AR CC
4.3 Chemical hazards – damp and mould							
<b>Concentration of biological agents (fungi, yeast and total bacteria)</b>	CFU/m <sup>3</sup> CFU: Colony Forming Units	B1-7: Use	In-use Handover and close-out	In situ air quality	French standard: AFNOR XP X 43-401	-	FS

<sup>195</sup> BASTA (2016) *About Basta* [online], available at: <http://www.bastaonline.se/about-basta/about-basta/?lang=en> [20/5/2016]

<sup>196</sup> SUNDHUS (2016) *Efficient solutions for conscious material choices* [online], available at: <https://www.sundahus.se/en/> [20/5/2016]

<b>Inspection classification of dampness and mould in building structures</b>	Rating or classification	B1-7: Use	Refurbishment In-use	Internal conditions	Member State rating systems e.g. Nordic proposal, classes 1-4	-	CC
<b>Mould Severity Index</b>	MSI score	B1-7: Use			Warm Front (UK)	-	CC
<b>Hazard category assessment for damp and mould growth</b>	Hazard rating	B1-7: Use			UK Housing Health and Safety Rating system	-	CC

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 6.5.2 Long list of macro-objective 4a supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>4.1 Hazardous substances – ventilation intake</b>							
Temperature	K	B1-7: Use	In-use	Internal conditions	In-situ measurements	-	FS
Relative Humidity	%	B1-7: Use	In-use			-	FS
Indoor CO <sub>2</sub> concentration	ppm	B1-7: Use	In-use			-	FS

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 7. Macro-objective 5: Resilience to climate change

### 7.1 Defining the macro-objective's scope and focus

#### 7.1.1 Policy and technical background to selection of the macro-objective

As was noted under macro-objective 1, the EU is committed under the UN Framework Convention on Climate Change to reduce its greenhouse gas emissions. A related aspect of climate change that is now also being addressed is climate change adaptation. This aims to ensure that society is resilient to the predicted adverse effects of future climate change.

An EU strategy on adaptation to climate change was published in 2013<sup>197</sup>. The strategy highlights the need for the 'climate proofing' of cities as well as physical infrastructure and assets. Major threats to buildings and constructions are identified as<sup>198</sup>:

1. Extreme precipitation;
2. Extreme summer heat events;
3. Exposure to heavy snow fall;
4. Rising sea levels increasing the risk of flooding.

The overheating of the built environment is also highlighted, with implications not just for building materials but also for the comfort and wellbeing of occupiers. The recast EPD Directive 2010/31/EU specifically addresses overheating, stating that:

*'...there should be focus on measures which avoid overheating, such as shading and sufficient thermal capacity in the building construction, and further development and application of passive cooling techniques, primarily those that improve indoor climatic conditions and the micro-climate around buildings.'*

The Commission anticipates that adaptation strategies are needed at local, regional, national and EU level. Due to the varying severity and nature of climate impacts between regions in Europe, most adaptation initiatives are envisaged as being taken at the regional or local levels. The ability to cope and adapt will also differ across populations, economic sectors and regions within Europe.

The JRC PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) analysed the possible impacts of climate change across Europe<sup>199</sup>. The results provided background information on climate adaptation and impacts to the 2013 EU Strategy on Adaptation to Climate Change. Selected climate change scenarios modelled for changes in temperature are illustrated in Figure 7.1.

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<sup>197</sup> COM(2013)216, Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *An EU Strategy on Adaptation to Climate Change*

<sup>198</sup> Commission Staff Working Document, *Adapting infrastructure to climate change*, SWD(2013) 137, Brussels, 16.4.2013

<sup>199</sup> Joint Research Centre (2014) *Climate change impacts in Europe: the JRC PESETA II project*, European Commission.



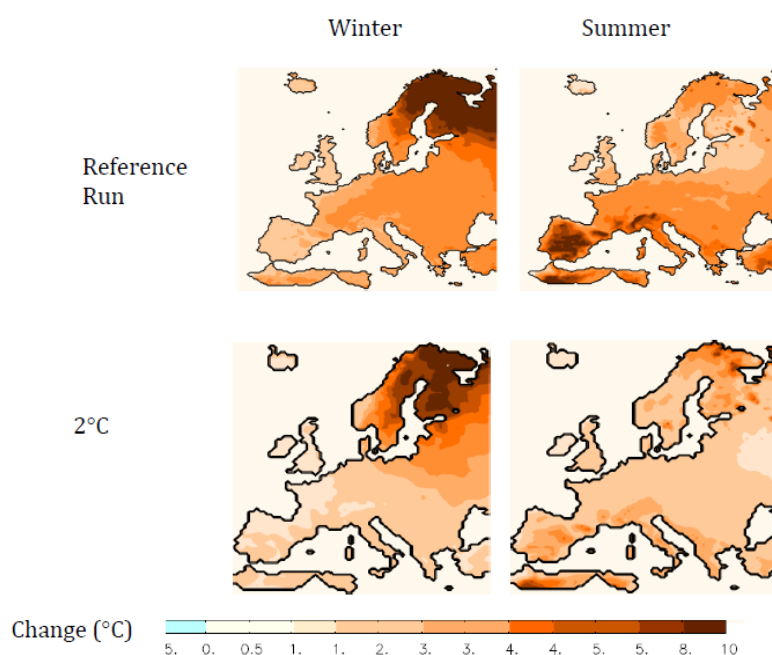


Figure 7.1 Seasonal (winter and summer) temperature change (°C) for 2071-2100, compared to 1961-1990

Source: JRC (2014)

One element of the model consisted of an assessment of the impact of changes in ambient temperature and rainfall on the EU's energy system, focusing on heating and cooling demand for residential and commercial sectors. Table 7.1 represents the projected energy demand for the EU and various sub-regions in two climate simulations. These model the change in 2071-2100 (also referred to as 2080s), compared to 1961-1990.

By the end of the century under the Reference scenario, overall EU energy demand is projected to fall by 13% but energy demand would rise by 8% in Southern Europe. This rise is accounted for by increased cooling demand. The modelling was steady state, so will not have accounted for localised urban heat island effects in towns and cities. Accompanying this projected change in energy demand, there is a projected significant increase in heat mortality, with the largest potential mortality increases from climate change occur in Mediterranean countries<sup>200</sup>.

Table 7.1 Modelled impact on EU energy consumption

	EU	Northern Europe	UK & Ireland	Central Europe North	Central Europe South	Southern Europe
Control	259,429	7,194	40,701	92,026	69,868	49,639
Reference change (%)	-13	-15	-14	-21	-16	8
2°C change (%)	-7	-11	-5	-11	-9	1

Units: ktoe/year

Source: JRC (2014)

<sup>200</sup> Joint Research Centre (2009) *Impacts of climate change in human health in Europe. PESETA-Human health study*, European Commission.

Further related work by the Joint Research Centre has focussed on the development of a 'heat wave magnitude index'<sup>201</sup>. Based on analysis of heat wave occurrence during the three study periods 1980–1990, 1991–2001, and 2002–2012, the index is intended to allow for a projection of the future occurrence and severity of heat waves. These projections would be according to selected IPCC pathways for future CO<sub>2</sub> concentrations.

### **7.1.2 The intended scope and focus**

The macro-objective is intended to encompass the futureproofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort. This would focus attention at the building level on actions to design-in resilience to projected climate change. This would have the potential to minimise risks to future property values and make properties more attractive and comfortable for occupiers.

In practical terms, the macro-objective will focus on thermal comfort, with the EU EPBD Directive highlighting the need to integrate the consideration of overheating into building standards. The tolerances of building designs to overheating is therefore likely to require attention. The scope could also encompass the potential positive influence of 'green infrastructure' at the building level, for which there is evidence that certain features can moderate temperatures around a building.

## **7.2 Cross-cutting scoping and investigation of the macro-objective's implementation**

### **7.2.1 National and regional initiatives**

#### **7.2.1.1 National regulations on thermal comfort and overheating**

As required by the EPBD, many member states already factor overheating risk into their National Calculation Methods. These vary between quasi dynamic simulations (e.g. CALENER, Spain) and quasi-steady state simulations (e.g. SBEM and SAP, UK). They are based on average present weather conditions.

The Building Performance Institute Europe (BPIE) analysed residential building thermal comfort regulations in eight Member States<sup>202</sup>. The eight Member States covered by the study were Belgium (Brussels Capital Region), Denmark, France, Germany, Italy, Poland, Sweden and the UK (England and Wales).

The study considered three factors that are linked to thermal comfort - air temperature, humidity and air velocity. The importance to human health of addressing both winter cold indoor temperatures and an increased risk of summer overheating are highlighted.

Indoor air temperature is the most commonly used indicator of thermal comfort, and five out of eight countries had a limit on overheating - with indicators differing by temperature and time limit. There are clear overlaps between the requirements identified for humidity and the control of mould - an aspect addressed by macro-objective 4a.

Four countries emphasise passive design measures to control overheating, with France and Germany having specific indicators which take several passive aspects into account. The French indicator determines the maximum operative

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<sup>201</sup> Russo, S., A. Dosio, R. G. Graversen, J. Sillmann, H. Carrao, M. B. Dunbar, A. Singleton, P. Montagna, P. Barbola, and J. V. Vogt (2014), *Magnitude of extreme heat waves in present climate and their projection in a warming world*, *J. Geophys. Res. Atmos.*, 119, 12,500–12,512

<sup>202</sup> BPIE (2015) *Indoor air quality, thermal comfort and daylight – analysis of residential building regulations in eight EU member states*.

temperature without recourse to comfort cooling. The German indicator establishes maximum solar gains.

Table 7.2. Comparison of thermal comfort regulations in eight member states

Member state	Summer thermal comfort requirements identified		
	Air temperature	Air velocity	Humidity
Brussels Capital Region	>25°C for <5% of the year	Summer: 0.24 m/s Optimum: 0.12 m/s	Elementary focus on limiting mould or damage
Denmark	>26°C for <100 hours of the year >27°C for <25 hours of the year	No specific requirements	Non-binding recommendation
France	TIC (Indoor Conventional Temperature) indicator - 28°C for mechanical ventilation - Differing limit values for natural ventilation	No specific requirements	No specific requirements
Germany	Maximum solar gains to avoid overheating for 10% of the year. Indoor temperature limits of 25 – 27°C (according to three climate zones)	-	DIN recommends maintenance of 30-70% range
Italy	Minimum internal cooling temperature of 26°C +/-2°C	Summer: 0.05 – 0.20 m/s	No specific requirements
Poland	Design to reduce the risk of summer overheating Window surface area threshold equation	Summer: 0.40 m/s	Summer relative humidity range 40-60% Thermal co-efficients for external walls to avoid water condensation
Sweden	Maximum internal temperature of 26°C	Outside of heating season: 0.25 m/s	No specific requirements
UK	Living areas: >28°C for <1% annual occupied hours of the year Bedrooms: >26°C for <1% annual occupied hours of the year NCM overheating assessment procedure	All year: 0.15 m/s	No specific requirements

Source: BPIE (2015)

There are examples of member states where options for more stringent compliance assessments of the risk of overheating, now and into the future, have been implemented. Estonia and the city of London are notable examples. In London there has been a focus on the urban heat island effect, described further in section 7.2.2.2.

In Estonia, since 2008, EPCs for offices and homes must be accompanied by compliance verification that the building complies with the thermal comfort requirements<sup>203</sup>. The requirement is defined as a maximum indoor temperature excess, expressed in degree hours (°Ch) over a given base temperature. The calculation period is for July and August, and only for occupied hours. A specific methodology was developed for designers which relies on a dynamic simulation. Buildings with cooling equipment and detached homes that meet specifications for window size, shading and openability are exempted.

### 7.2.2.2 Initiatives addressing the urban heat island

The urban heat island effect is an additional factor to take into account when modelling the external temperatures around a building. This is because the temperature in an urban area can be elevated compared to rural areas due to a combination of:

- vehicle exhaust,
- building air conditioning heat rejection,
- street canyon geometry,
- reduced evapotranspiration by vegetation and,
- absorption and re-radiation of heat by roads, paving and structures.

Recognising the significance of this effect, a number of cities have put in place initiatives to either support designers to take better account of this effect, or to require building designers to integrate green infrastructure measures to attenuate the effect.

The Greater London Authority has developed a dataset which has been published by CIBSE as TM49. This also comes together with an improved methodology to model overheating risk based on a 'weighted cooling degree hour'. This provides Design Summer Year (DSY) data for three different areas of Greater London. The data covers three years when heat waves occurred (1976, 1989 and 2003) representing the varying severity of these events. Figure 7.2 indicates the predicted variations for these time periods.

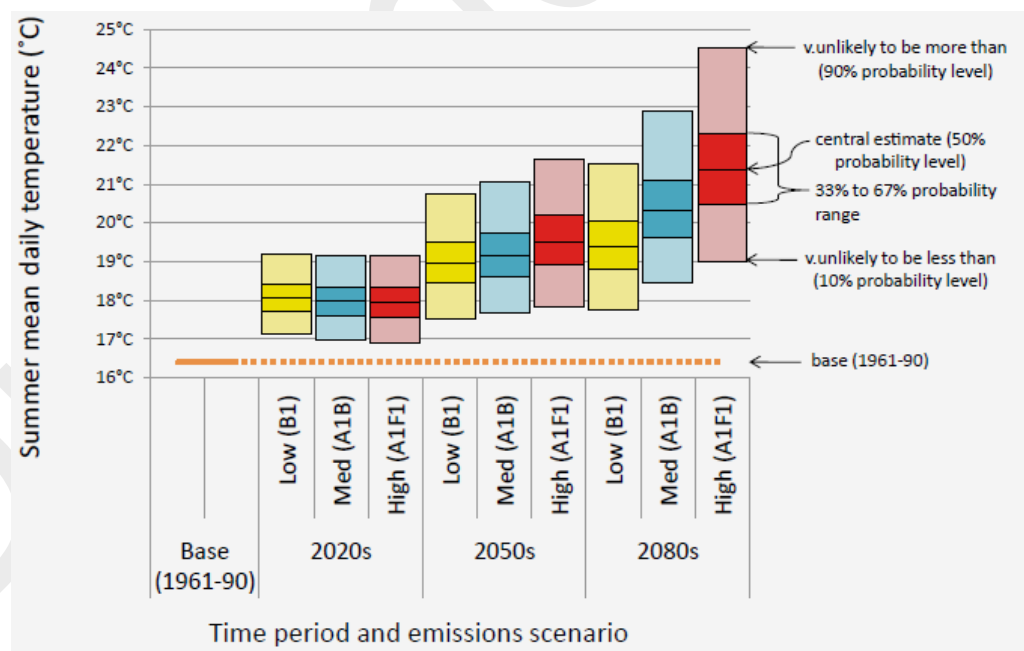


Figure 7.2 London summer mean daily temperature (oC) - probabilistic climate profile based on UKCIP09 data

<sup>203</sup> Simson.R, Kurnitski.J and Maivel.M, Summertime overheating prevention requirements and results in Estonia, REHVA Journal, October 2015

Source: Zero Carbon Hub (2015)

One potential weakness of data covering such large city areas is that it still does not take account of localised microclimate extremes that may occur. Although modelling tools have been developed and applied to study specific urban locations, they are generally still research tools. Computational Fluid Dynamic (CFD) simulations is generally used, although specific software has been developed such as CitySim (University of Lausanne).

Research has also been undertaken in the Spanish cities of Zaragoza and Valencia to study the heat island effect. In Zaragoza air temperature maps have been developed <sup>204</sup>. These have enabled the effect of the surrounding topography and the different urban forms and densities within the city to be analysed. In Valencia, the University of Valencia and Bipolaire have studied thermal comfort within urban spaces between buildings <sup>205</sup>. This has included the monitoring of conditions and the surveying of users of the urban spaces.

## 7.2.2 Building permitting and planning requirements

### 7.2.2.1 The use of green factors to moderate the urban microclimate

A wide range of evidence suggests that the presence of vegetation, and in particular trees, in the urban environment can play a significant role in moderating summer temperatures <sup>206</sup>. Analysis at building level of the cooling efficiency of different combinations of vegetation suggest that this due to a combination of shading, evapotranspiration and (where combined) non-sealed surfaces (Shashua-Bar et al 2009) <sup>207</sup>. Together, depending on the climate and the type of vegetation, this can act to moderate air temperatures, reduce surface temperatures and re-radiation. Related possible areas of focus for attention in seeking to develop indicators are illustrated in Figure 7.3.

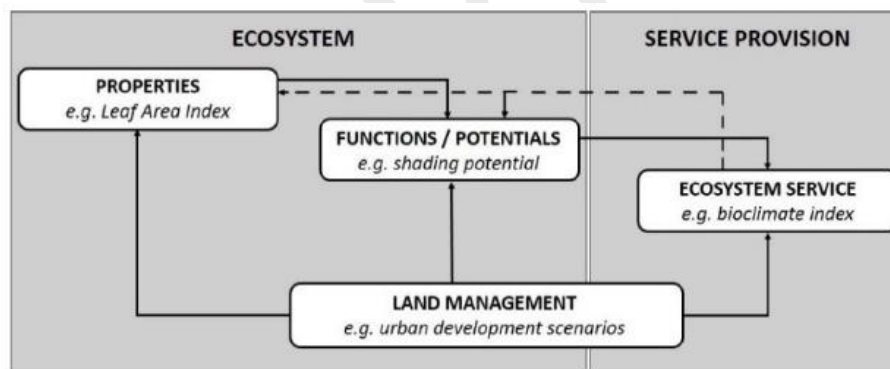


Figure 7.3 Areas of potential focus for indicators of microclimate regulation and ecosystem services provided by vegetation

Source: Takács et al (2014)

<sup>204</sup> José M. Cuadrat Prats, Sergio M. Vicente-Serrano y Miguel A. Saz Sánchez, *Los efectos de la urbanización en el clima de Zaragoza (España): La isla de calor y sus factores condicionantes*, Boletín de la A.G.E. N.º 40 - 2005, págs. 311-327

<sup>205</sup> Bipolaire architects and the University of Valencia (2015) *TREELAB: Urban Laboratory for climate and psychological aspects*, project report.

<sup>206</sup> Takacs.A, Kiss.M and A.Gulyass, *Some aspects of indicator development for mapping microclimate regulation ecosystem service of urban tree stands*, Universitatis Szegediensis, Tomus, Acta Climatologica et Chlorologica, 47-48, 2014, 99-108

<sup>207</sup> Shashua-Bar.L, Pearlmutter.D and Erell.E, The cooling efficiency of urban landscape strategies in a hot dry climate, *Landscape and urban planning* 92(2009) 179-186

A number of European cities have developed so-called 'green factors' as planning tools with the main aims being to address the urban heat island effect, increase water retention and increase urban biodiversity<sup>208</sup>. Given that these aspects are complex to model, green factors are designed to act as a proxy for the benefits of green infrastructure (e.g. plant evapotranspiration, soil water retention).

The methodology used to calculate a green factor varies according to the aims and objectives of the local planning authority. In general, they consist of a series of weighting factors that reflect the relative contribution of a buildings surface area and its surrounding spaces to the planning objective. Below the variations in methodology applied in Berlin, Malmö and Stockholm are briefly compared and contrasted.

In Berlin, a 'Biotope Area Factor' (BAF) is used to reduce soil sealing and increase green cover in higher density urban areas<sup>209</sup>. It is applied as a planning requirement to all buildings in specific inner urban areas. The Berlin factor is largely determined based on the proportion of building and space where there is soil sealing (see formula 1). It does not account for the extent of vegetation that may be planted in the soil i.e. it does not reflect leaf transpiration cooling capacity.

$$BAF = \frac{\text{ecologically effective area (m}^2\text{)}}{\text{area of the public land}} \quad (1)$$

In Malmö, a 'Green Space Factor' (GSF) is combined with a 'Green Point' system<sup>210</sup>. These have been applied as permitting requirements for specific new areas of development (see formula 2). The GSF is weighted to take into account the extent of soil sealing, the depth of soil and the extent of vegetation (e.g. mature trees have a greater weighting). The points additionally encourage biodiversity features in spaces within, between and on buildings.

$$GSF = \frac{(\text{area A x factor A})+(\text{area B x factor B})+(\text{area C x factor C})+\text{etc.}}{\text{total courtyard area}} \quad (2)$$

Comparative studies of green factors have explored the extent to which these methodologies are robust and transferable between towns and cities<sup>211</sup>. A number of issues are identified:

- Scientific basis: The Berlin factor, for example, appears not to have been updated to reflect the latest scientific knowledge, and performance monitoring has not been carried out.
- Specificity to the urban location and biogeography: In both Berlin and Malmö, the calculation is adjusted to reflect the prevailing density, building types and potential site area available for green features in different parts of the city. The applicability of the weighting factors in different climatic zones is a further issue.
- Trade-offs and benefits: There is the need to further consider the relative contribution of such a factor in different climate zones and the possible trade-offs – for example, greater water demand for irrigation.

Farrugia et al (2013) attempt to address the first and second point in their study to transfer such a factor to the UK city of Southampton. Habitat mapping instead

<sup>208</sup> Farrugia,S, Hudson.M.D and McCullogh.L, *An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure*, *International Journal of biodiversity science, ecosystem services & management*, 2013, Vol 9, No 2, 136-145.

<sup>209</sup> Climate ADAPT (2014) *Berlin biotope area factor – implementation of guidelines helping to control temperature and runoff*, European Environment Agency.

<sup>210</sup> Kruuse.A, *the green space factor and the green points system*, GRaBs Expert paper 6, EU INTERREG project, TCPA, April 2001

<sup>211</sup> Keeley.M, *The Green Area Ratio: an urban site sustainability metric*, *Journal of environmental planning and management*, 2011, 54:7, 937-958

of surface type mapping was used to more accurately reflect cooling potential. A combination of a dataset developed by Gibson (2009)<sup>212</sup>, the EEA Corine Land Cover database and, where necessary, additional supporting scientific evidence, was used as the starting point for establishing a non-geographically specific, greenspace classification and an accompanying new set of weighting factors.

### **7.2.3 Private and public sector building practices**

#### **7.2.3.1 Development of tools to address overheating**

Given that the scope of the macro-objective is to address the potential health impacts of future climate change then, as demonstrated by the excess deaths that occurred across Europe as a result of the 2003 heat wave, a focus on residential buildings becomes appropriate.

Residential overheating has been a focus of attention in the UK for both energy efficient, air tight new homes and in order to identify adaptation issues for existing properties. Both the UK Government<sup>213</sup> and the Zero Carbon Hub<sup>214</sup> have explored the risks and associated assessment methods.

A simplified definition of overheating in a building has up until now been used in the UK – for example, in standards for social housing. Based on CIBSE Guide A, an assessment is made of the period of time that the temperature exceeds a specified value (e.g. 28°C for >1% of working hours or occupier hours). Nicol et al (2013)<sup>215</sup> highlight a number of weaknesses with this methodology:

- It does not take into account the difference between mechanically cooled buildings and 'free running' (naturally ventilated) buildings. In the case of the former, it is easier to adjust setbacks, but in the case of the latter temperature limits may be more adaptive;
- The threshold does not take into account the severity of the overheating, so 8 hours over by 1°C may be more acceptable than 4 hours by 2°C.
- Such a criterion is sensitive to the assessment method for the temperature, and in particular to the resulting distribution curve.
- Perception of overheating is also important, including factors such as room size, effectiveness of ventilation and number of occupants.

They highlight that for natural ventilated buildings, the more appropriate assessment methodology reflects those described in EN 15251 and ASHRAE 55, whereby indoor comfort is a function of the outdoor temperature. EN 15251 is described further in Section 7.2.4. The CIBSE TM52 methodology is also briefly described.

The work of the Zero Carbon Hub is particularly relevant to this study because it reviewed a range of different assessment methods, as well as considering the modelling of future climate scenarios. One of their main conclusions was that residential and non-residential building design tend to be very different, with the use of Dynamic Simulation Modelling being rare for residential buildings. The additional benefit of applying DSMs to residential buildings was questioned.

The Zero Carbon Hub identified that future climate data for 2030s, 2050s and 2080s is readily available in the UK for 14 major cities and on an hourly average basis, as well as for a 'Design Summer Year' (DSY). An important note is the

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<sup>212</sup> Gibson B. (2009) *The effect of land cover and topography upon satellite derived land surface temperature, and its relationship with urban air pollution and population* [master's project]. Southampton: School of Civil Engineering and the Environment, University of Southampton.

<sup>213</sup> UK Government (2012) *Investigation into overheating in homes*, Department for Communities and Local Government, Study carried out by AECOM.

<sup>214</sup> Zero Carbon Hub, *Assessing overheating risk*, March 2015, UK

<sup>215</sup> Nicol.F, Humphreys.M and Roaf.S (2013) *Adaptive thermal comfort – principles and practice*, Earthscan

potential for inconsistency, as there are three emission scenarios and the fact that different sources for the data use different baseline references (1961-1990 or 1980-2012) which could lead to an overestimation of overheating risk. Reference is made to two areas of practical implementation, which are examined in further detail in section 7.3 and 7.4 of this Chapter:

- BREEAM UK non-residential criterion which requires assessment based on UKCIP09 climate projections and according to the building design and servicing strategy:
  - for naturally ventilated buildings averaged data benchmarked against the 2050s medium emissions scenario
  - for mechanically ventilated and mixed mode buildings averaged data benchmarks against the 2030s medium emissions scenario
- Design for Future Climate (D4FC) project which involved approximately 50 building projects, the findings of which are analysed further within the field Studies in Section 7.3.

The Zero Carbon Hub noted that whilst the residential National Calculation Method in the UK includes simplified assumptions for overheating which assess the risk based on summer monthly average temperatures, it does not reflect the relationship between internal comfort and external temperatures. Moreover, they also highlighted the problems that can occur if the standard heat gain profiles are substituted by the designer, in particular assumptions that may be made about residential occupancy levels. The newer CIBSE TM52 methodology is highlighted as being relevant to the future design of homes (see Section 7.2.4).

### **7.2.3.2 Initiatives to highlight the future risk to property investments**

The potential for future climate change to pose future risks and liabilities for property investments is now being addressed by reporting tools such as GRESB and supported technically by the initiatives of organisations such as the RICS.

RICS has developed a 'climate risk toolkit'<sup>216</sup> which focusses on eight EU countries – Belgium, Czech Republic, France, Germany, Greece, Ireland, Spain, Sweden and the UK. The toolkit provides predictions for 2050 for mechanically ventilated and naturally ventilated non-residential buildings, which include office buildings. The predictions are based on dynamic simulations for hypothetical buildings built according to local regulations in 1961, 1991 and 2011, and for each of 39 separate locations.

To ensure consistency, the simulations were carried out for the same building forms, use intensity and fuel price in all locations using:

- EnergyPlus software,
- The world weather file generator of a UK university and,
- The thermal comfort calculation methodology defined by EN 15251.

The quality of construction, efficiency of the heating and cooling systems and the thermal efficiency of the building fabric was varied according to the age of construction. This allowed the possible extent of the risk based on the age of the asset to be predicted, expressed in terms of running costs. This highlighted the greatest risk being in Germany, Greece and Spain, but with significant changes also predicted for southern France and southern Sweden (see Figure 7.4).

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<sup>216</sup> RICS, *Climatic risk toolkit – the impact of climate change in the non-domestic real estate sector of eight European countries*, March 2015



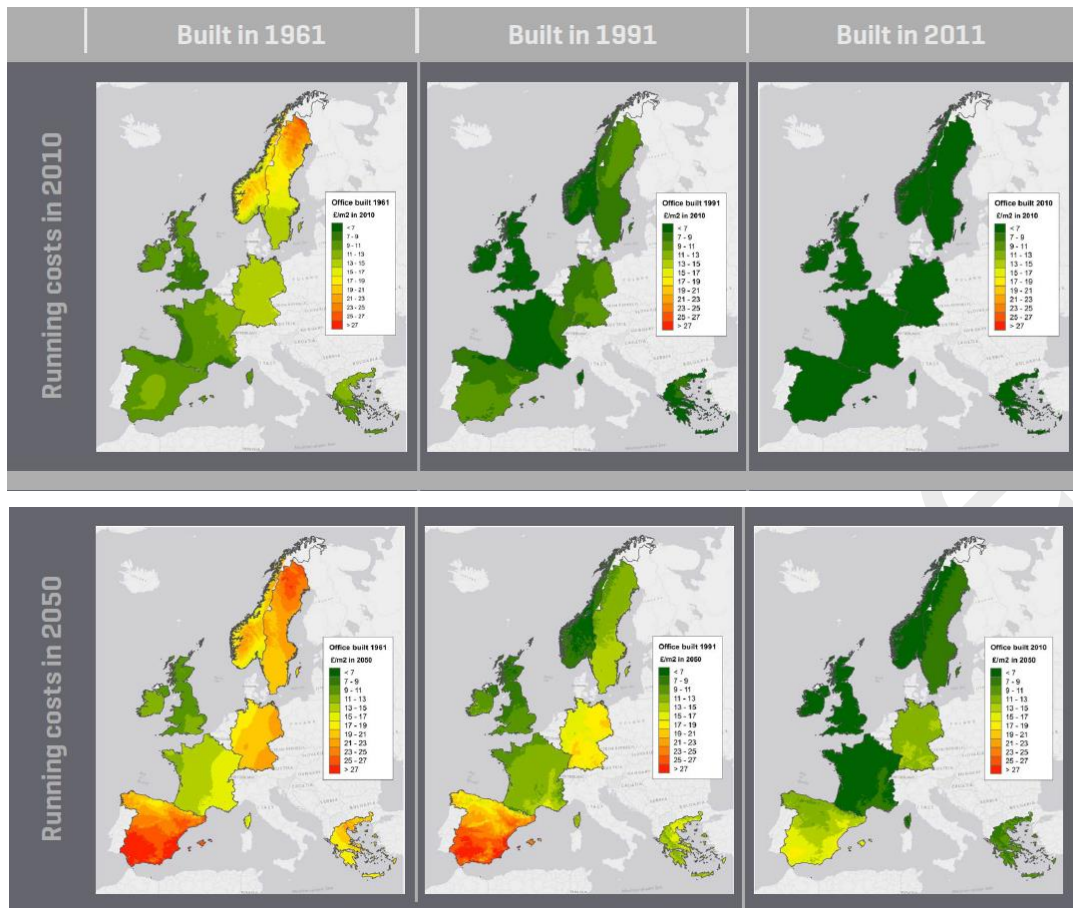


Figure 7.4 Comparison of running costs for 2011 and 2050 for an office building constructed in 1961, 1991 and 2011

Source: RICS (2015)

## 7.2.4 Standards and harmonisation initiatives

### 7.2.4.1 EN 15251 and EN ISO 7730

Two EN standards are of relevance to this macro-objective – EN 15251 which sets temperature ranges for the performance of mechanically and naturally ventilated buildings, and EN ISO 7730 which provides methods to predict the degree of thermal discomfort that building occupants may feel. As noted in Chapter 6, EN 15251 will be superseded by prEN 16798.

The methods described in EN 15251 and EN ISO 7730 are widely used and provide predictive models for the following two aspects:

- Predicted Mean Vote (PMV)
- Predicted Percentage of dissatisfied (PPD)

Calculation relies on a number of different input assumptions for six 'thermal parameters', which means that there is some scope for interpretation on a case by case basis. The parameters are clothing, activity level, air and mean radiant temperature, air velocity and humidity.

The standard provides methodologies for offices and residential buildings, recognising that there are differences in level of thermal comfort that people experience in their homes and in an office. Key differences that distinguish thermal comfort in homes are identified as follows:

- People have different activity levels at home compared to occupants in office buildings and the activity level can more easily be adapted to the situation;
- At the same temperature, people feel warmer in their homes than in an office situation - people tend to evaluate rooms as being warmer due to the presence of furnishing;
- At home, people also accept a wider range of temperatures in their indoor environment because they have to pay for their own energy bill and they can more easily adjust to temperature differences (e.g. by changing clothing and adapting behaviors).

EN 15251 indicates a design maximum temperature for HVAC operation, as well as acceptable indoor temperatures for buildings without mechanical cooling systems – which are specified as being applicable for offices and residential buildings. The method relates indoor temperatures to the outdoor running mean temperature and assumes that manual ventilation is available to occupants i.e. openable windows.

It is important to note that the use of Predicted Mean Vote (PMV) for naturally ventilated buildings has been criticised, amongst others by Nicol et al (2013)<sup>217</sup>. Comparisons of the PMV and the actual comfort votes of occupants in field studies of buildings have shown that their level of discomfort tends to be overestimated by this method (see Figure 7.5). This anomaly is largely cited as being due to the assumed relationship between the outdoor temperature and the indoor comfort temperature. The range of temperatures that people can find comfortable also tends to be much wider.

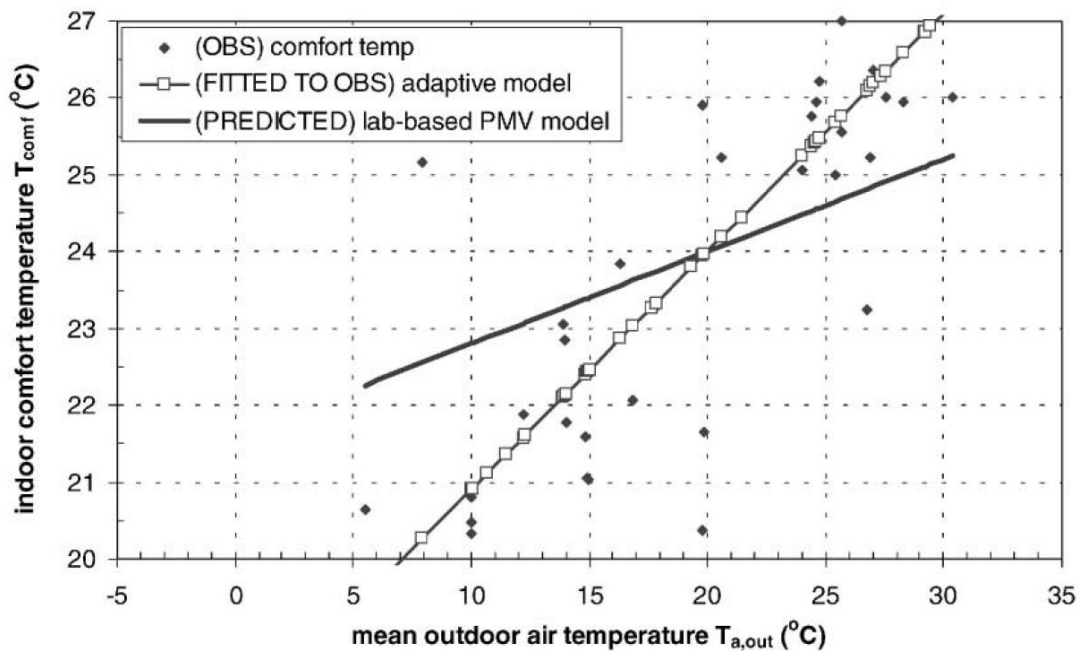


Figure 7.5 Comfort temperature predicted by PMV compared with the observed (OBS) comfort temperature votes measured in field studies.

Source: de Dear and Brager (2002)

Whilst Nicol et al (2013) put forward a number suggestions for the sources of error in the PMV approach, an alternative methodology to address them does not currently appear to be available.

<sup>217</sup> Nicol.F, Humphreys.M and Roaf.S (2013) *Adaptive thermal comfort – principles and practice*, Earthscan

#### **7.2.4.2 EN 15643-2 thermal comfort method**

As part of the EN 15643 series of standards that establish a framework for the sustainability assessment of buildings, CEN/TC 350 has developed a standard for assessing the social performance of buildings. The standard includes a specific requirement on thermal comfort which is based on the methodology in EN 15251 and EN ISO 7730.

Recognising the importance of occupier control of comfort conditions, it also provides a checklist of aspects which can be used to assess the level of control that is made available:

- operative temperature at a building level can be controlled [yes/no];
- operative temperature in individual rooms can be controlled (if yes: manually or automatically) [yes/no];
- is there measurement and display of temperature in the building and/or individual rooms? [yes/no];
- humidity at a building level can be controlled [yes/no];
- humidity in individual rooms can be controlled (if yes: manually or automatically) [yes/no];
- room air velocity and distribution at a building level can be controlled [yes/no];
- room air velocity and distribution in individual rooms can be controlled (if yes: manually or automatically) [yes/no].

#### **7.2.4.3 CIBSE TM52**

The TM52 methodology is relevant to free running (naturally ventilated) buildings<sup>218</sup>. It is based on the 'adaptive comfort' approach, whereby it is assumed that occupants adjust their perception of comfort in function of the external temperature, so during summer, for example, occupants will accept higher temperatures and will adapt their clothing to reflect this.

The methodology is based on the difference between the predicted internal temperature and the external 'running mean' temperature based on weather files. The model takes into account occupancy patterns and internal gains. Three criteria are laid down, two out of three of which must be met in order to comply:

- Threshold temperature exceeded for more than 3% of the occupied hours per year
- Daily weighted overheating of more than 6 degree hours per year
- Temperature exceeds the threshold upper limit (dynamic according to the building and the weather file)

The methodology requires use Design Summer Year (DSY) weather files, but alternative data can be used.

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<sup>218</sup> CIBSE (2013) *TM52 The limits of thermal comfort: avoiding overheating in European buildings*.

## 7.3 Findings from investigation of the selected field study clusters

The macro-objective B5 field studies consist of three clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- Design for Future Change: Office building adaptation modelling (UK);
- Knowledge for Climate: Residential building adaptation modelling (Netherlands);
- IDOM and New4Old: Office and residential building adaptation modelling and design (Spain);

For each cluster, the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

### 7.3.1 Cluster 1: Design for Future Climate (D4FC)

#### 7.3.1.1 Background and context to selection of the cluster

The Design for Future Climate competition was launched by the Technology Strategy Board (TSB, now Innovate UK) in 2010 to provide funding for the development of adaptation strategies for new build and refurbishment projects.

In total, 45 projects received funding through the project. These projects developed adaptation strategies for a range of new build and refurbishment projects, and identified many effective measures for adapting to the effects of climate change in UK. Three case studies from the D4FC database were selected for this field study:

*Case 1: Co-operative headquarters by Buro Happold:*

Climate Change risk assessment was carried out using UKCP09 climate projections for 2030s and 2050s. Dynamic thermal modelling was used to predict the energy use and internal comfort for these future scenarios.

*Case 2: 100 City Road, London by ARUP:*

Dynamic Thermal Modelling was used to make comparisons between 2005 Test Reference Year (TRY) and UKCP09 climate projections for 2020, 2050 and 2080.

*Case 3: Admiral Insurance HQ, Cardiff by Glen Howell:*

Detailed energy modelling was carried out upon the building according to an accurate specification of its current design and use profile. This was completed under a base case (present) climatic scenario and for three future scenarios; 2030, 2050 and 2080, created by Exeter University, from the UKCP09 datasets.

*Table 7.3 D4FC office building selected for analysis*

Building	Climate zone, Location	Typology	Type	Scale	Stage
Co-operative HQ, Buro Happold	Central Europe, Manchester (UK)	Office, medium-rise	New-build	30000 m <sup>2</sup>	In-use
100 City Road, ARUP	Central Europe, London (UK)	Office, high-rise	New-build	16000 m <sup>2</sup>	In-use
Admiral HQ, Glen Howell	Central Europe, Cardiff (UK)	Office, medium-rise	New-build	18580 m <sup>2</sup>	In-use

### 7.3.1.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

The methodological framework used in the D4FC projects is based on the four stage approach of Modern Built Environment – Knowledge Transfer Network<sup>219</sup>:

- Identify risks to core business, supply chain and wider network
- Classify climate-related risks
- Identify climate change adaptation strategies
- Assess the value of adaptation options

A key resource for the D4FC projects are the UK Climate Projections published in 2009 (UKCP09)<sup>220</sup>. UKCP09 provides future climate projections for land and marine regions as well as observed (past) climate data for the UK. Climate projections for 2030s, 2050s and 2080s scenarios provide detailed predictions for future temperature and solar radiation. In the selected three cases the performance of the proposed different adaptation measures was assessed by conducting a dynamic thermal simulations using IES Virtual Environment.

CIBSE Guide A (2006) is used as the main reference standard for the thermal comfort model and the following criteria for thermal performance were applied:

- no more than 5% of occupied hours exceeding 25°C; and,
- no more than 1% of occupied hours exceeding 28°C.

### 7.3.1.3 How performance improvements were measured

*The main indicators in this field study are identified as:*

- Temperature [°C]
- Overheating hours [h]

Operative temperature and temperature limits are used to assess the thermal comfort:

- Operative temperature is defined as the average of the mean radiant temperature and ambient air temperature, weighted by the heat transfer coefficients for radiation and convection.
- Temperature limits are defined and calculated based on neutral temperature (the temperature at which a human feels comfortable, and it differs for each residential typology).

When the operative temperature exceeds the threshold temperature an overheating hour is registered, and it is then calculated as the summation of the number of hours that the operative temperature is above the upper limit. The results on temperature level and overheating hour indicate that the studied buildings tend to be more climate resilient by implementing climate specific adaption measures. An example is given in Figures 7.6a and b of a comparison made between the operative temperatures under different climate profiles (2005 and 2050s).

<sup>219</sup> MBE, KTN, Guidance for making the case for climate change adaptation in the built environment, 2013

<sup>220</sup> <http://ukclimateprojections.metoffice.gov.uk/21678>

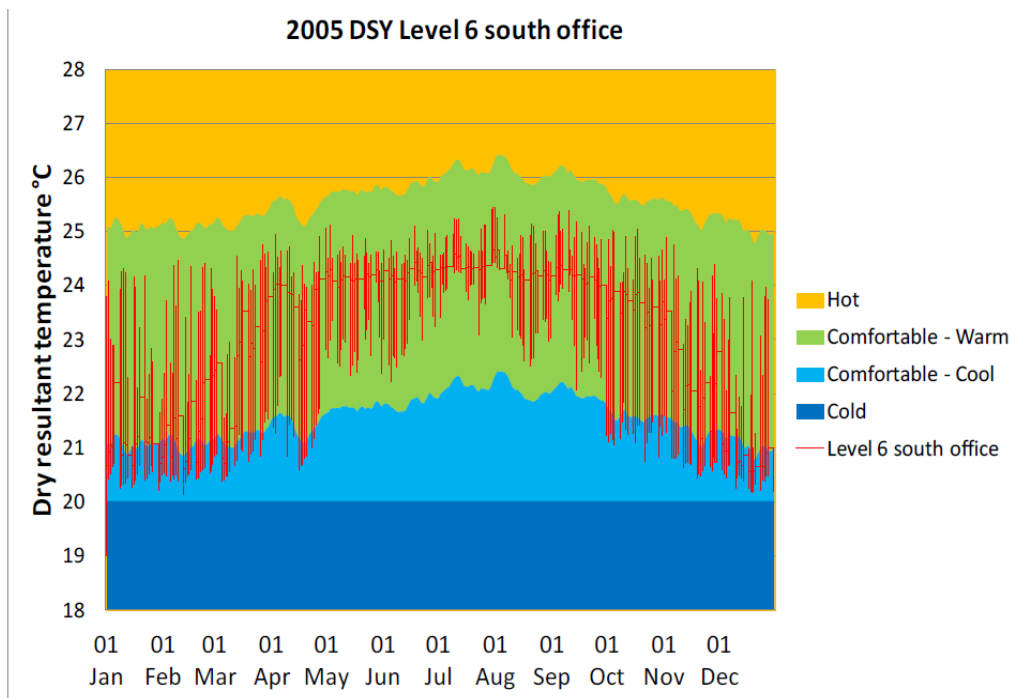


Figure 7.6a Indicative simulation results for the Co-operative Head Office (Manchester) based on 2005 data

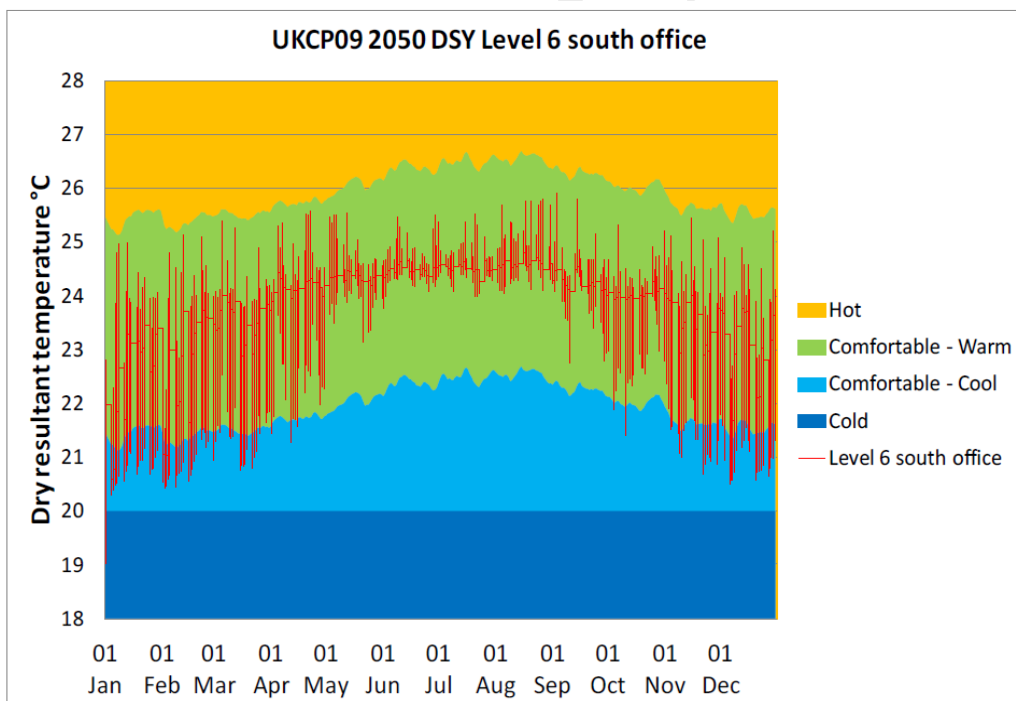


Figure 7.6b Indicative simulation results for the Co-operative Head Office (Manchester) for the 2050s scenario

Source: Ren et al (2012)<sup>221</sup>

<sup>221</sup> Ren, M., Shankland, N and Brayshaw, V (2012). *The Co-operative Head Office Climate Change Adaptation Study Final Report*.

In addition, a better energy performance could come at the expense of more overheating hours, and this is considered as a trade-off between operational energy use and thermal comfort, which links to macro objective B1 - Greenhouse gas emissions from building life cycle energy use.

This was analysed in the case study of Admiral HQ and the results showed that lowering the cooling set point can be used to reduce building's space conditioning demand, and implementing this method assumes no extra cost. However, increasing the set point up to 28 °C may have a considerable impact upon the comfort levels within the building. Thus, in making this adaptation, care must be taken to find the optimum, tolerable level, balanced against the productive output of the workforce.

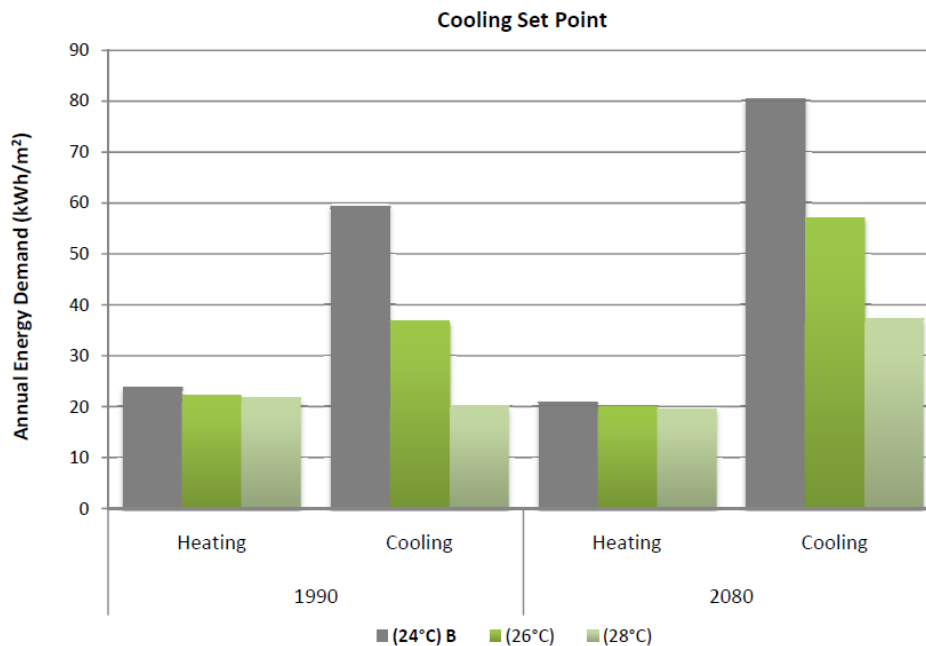


Figure 7.7 Indicative simulations of the additional heating and cooling energy demand for the 1990s and 2080s climate profiles for Admiral HQ, UK

Source: Beddoe, N (2012)<sup>222</sup>

On this point, it was noted that as external temperatures are expected to rise, it is possible that people's tolerance to higher temperatures may increase, making such a change more acceptable. Increasing the maximum summer temperature to a higher level may therefore be possible (according to the adaptive comfort approach) as occupants are likely to adapt to higher temperatures as the climate warms.

#### 7.3.1.4 Implementation experience of practitioners involved with delivery of the improvements

It can be seen that there is a large dependency on the availability of future climate data for the dynamic simulation. UK has conducted solid research on projection of future climate profile. Design Summer Year data series were created primarily for assessing summer overheating risk and are used in this field study. For some EU countries, this type of climate projection study might not be available. Besides, uncertainties in the projections cannot be ignored.

IES-VE has a wide range of modules that can carry out steady state and dynamic thermal calculations. Compared to other tools, IES-VE is more focused on building

<sup>222</sup> Beddoe, N. (2012). *Design for Future Climate – Developing an Adaptation Strategy Admiral Headquarters Cardiff*.

fabric and dynamic performance evaluation. It has some limits on modelling complex HVAC systems and control strategies. For the purpose of this adaptation study, IES-VE is a suitable tool for assessing indoor environment.

However, based on the experience from this field study, IES-VE does not appear to accurately reflect the implications of exposing thermal mass. In this sense, this software appears to be somewhat rudimentary in assessing passive design strategies involving thermal mass and, hence, it may not be suitable for use to address buildings adopting this design approach.

One last remark is that dynamic simulation can be time intensive/costly and expertise-demanding in practice, but it makes sense to conduct dynamic simulation for large scale project, especially office buildings.

### 7.3.2 Cluster 2: Knowledge for Climate (K4C)

#### 7.3.2.1 Background and context to selection of the cluster

The research presented in this field study has been funded by the Dutch Knowledge for Climate Research Program and was carried out by partners within the Climate Proof Cities research consortium. The research is conducted within the Climate Proof Cities (CPC) research consortium, which is one of the research consortia investigating the climate vulnerability of urban areas and the development and effectiveness of climate change adaptation measures.

The study quantifies the effectiveness of climate change adaptation measures applied at the level of building components for three generic residential buildings as commonly built in the Netherlands:

1. detached house;
2. terraced house;
3. apartment.

The numerical study involves new residential buildings that are built according to the building regulations and common practice in 2012, and renovation of the current building stock that were constructed in the 1970s, which have a lower thermal resistance of the opaque and transparent parts of the building envelope.

*Table 7.4 Residential buildings analysed in the K4C study*

Building	Climate zone, Location	Typology	Type	Scale	Stage
Detached house	Central-Europe, Netherlands (NL)	Residential, detached	Existing	-	Simulation
Terraced house	Central Europe, Netherlands (NL)	Residential, terraced	Existing	-	Simulation
Apartment	Central Europe, Netherlands (NL)	Residential, apartment	Existing	-	Simulation



### **7.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

The investigated passive climate change adaptation measures included: increased thermal resistance of the building envelope, changed thermal capacity, increased short-wave reflectivity (albedo value), vegetation roofs, solar shading and additional natural ventilation.

To assess the performance of the six different adaptation measures, dynamic thermal simulations were conducted by the researchers using EnergyPlus, an open-source energy simulation tool used for thermal calculations. The hourly weather profile was measured during 2006 in De Bilt, the Netherlands.

This year is known for the occurrence of several heat waves, therefore it is considered as a representative year with summer temperatures that will probably occur more often in the future as a result of climate change. ASHRAE Standard 55 is the main reference standard used for the thermal comfort model and criteria for thermal performance target.

The proposed target in this field study is to maintain the operative temperatures below temperature limits in different thermal zones (e.g. bedroom, living room), and there is no specific target on overheating hours used in this field study.

### **7.3.2.3 How performance improvements were measured**

*The indicators in this field study are identified as:*

- Temperature [°C]
- Overheating hours [h]
- Degree hours [°C\*h]

The most relevant indicators are temperature and overheating hours. Operative temperature and temperature limits are used to assess the thermal comfort: operative temperature is defined as the average of the mean radiant temperature and ambient air temperature, weighted by the heat transfer coefficients for radiation and convection; and temperature limits are defined as the minimum value between 26°C and the calculated neutral temperature (the temperature at which a human feels comfortable, and it differs for each residential typology).

An example of the temperature in the detached house is given in Figure 7.8 to show the operative temperature and upper limits. When the operative temperature exceeds the threshold temperature, an overheating hour is registered, and it is calculated as the summation of the number of hours that the operative temperature is above the upper limit. Degree hours are the product of the other two indicators. Based on the simulated results of proposed indicators, it is shown that exterior solar shading and additional natural ventilation are the most effective climate change adaptation measures.

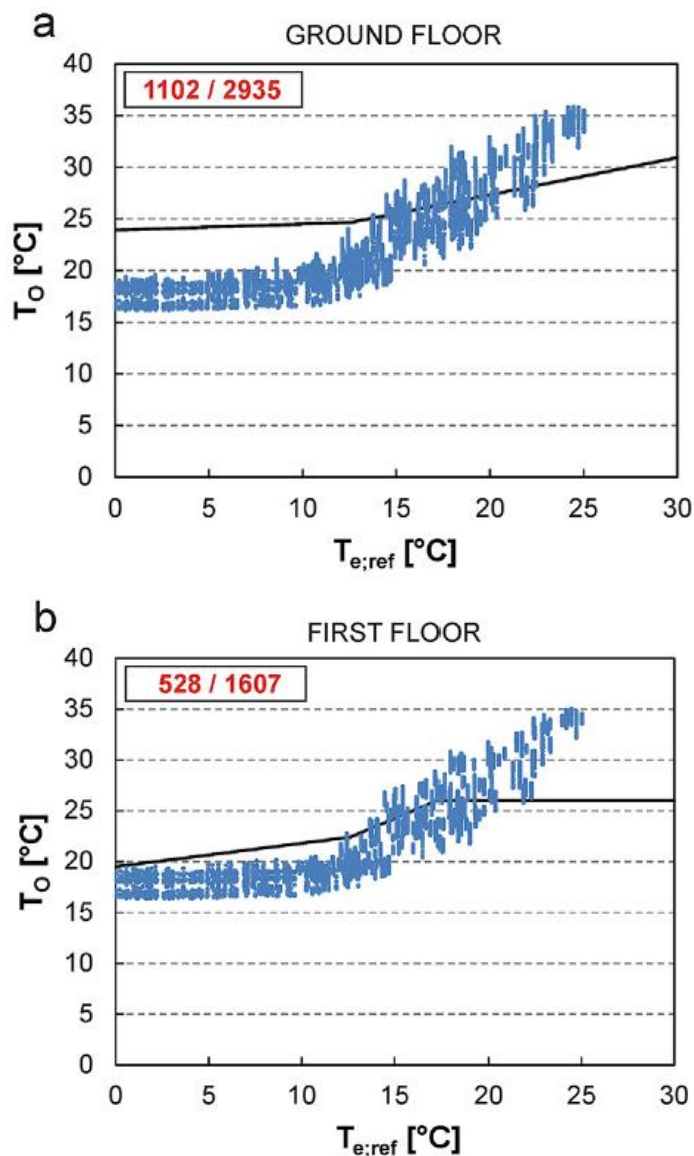


Figure 7.8 Example temperature variances for the detached house by floor

Source: Van Hooff et al (2015)<sup>223</sup>

The number of overheating hours in residential buildings that are built according to 2012 building regulations is higher than for the buildings from the 1970s, and it may be explained by the higher thermal resistance of the former, which reduces the heat transfer through the envelope once the air inside the building has been heated by solar radiation through the transparent parts of the building envelope.

Differences in the number of overheating hours also occur between different types of residential buildings. The number of overheating hours is significantly larger for the upper most apartment in the building due to the heat transfer through the roof of both the living room and the bedrooms.

In addition, a better energy performance could come at the expense of more overheating hours, and it can be considered as a trade-off between operational energy and thermal comfort, which is closely related to macro objective 1 - Greenhouse gas emissions from building life cycle energy use.

<sup>223</sup> Van Hooff, T., Blocken, B., Hensen, J.L.M., Timmermans, H.J.P. (2015) *Reprint of: On the predicted effectiveness of climate adaptation measures for residential buildings*

### 7.3.2.4 Implementation experience of practitioners involved with delivery of the improvements

The dynamic simulation was conducted by the researchers in this case study. EnergyPlus has been validated extensively for thermal calculations. The results obtained in EnergyPlus showed a very good agreement with analytical solutions and results obtained with other airflow network models.

The proposed indicators appear to be suitable for residential buildings. Residents have different activity levels than occupants in office building and the activity level can more easily be adapted to the situation. Moreover, residents also accept a wider range of temperatures in their indoor environment because they have to pay for their own energy bill and they can more easily adjust to temperature differences (e.g. by changing clothing and adapting behaviors).

Another value of this case study is the fact that climate data from a year with heat waves is used to represent projected climate data, and this is certainly an interesting alternative to using predicted weather profiles which might include more uncertainties.

The methodology used appears robust in terms of its ability to assess the resilience to climate change. However, one potential concern is that dynamic simulation can be time intensive/costly and expertise-demanding in practice. Therefore, it makes sense to conduct dynamic simulation for large scale projects, but may not be practical for every single building project, especially for residential buildings.

### 7.3.3 Cluster 3: IDOM and New4Old (Spain)

#### 7.3.3.1 Background and context to selection of the cluster

The Green Building Council Spain (GBCS) identified three projects in Spain that have taken into account future projections for climate change and related potential influence of the urban heat island effect when modelling a building's thermal performance and comfort levels.

IDOM is an international engineering, architecture and consulting firm. IDOM Spain uses future case scenarios when making energy simulations. Two case studies selected for detailed analysis are the IDOM headquarters in Bilbao (completed in 2011) and the IDOM headquarters in Madrid (completed in 2010).

The LIFE+ Project New4Old intends to prove that it is possible to design an energy retrofitting methodology for the most energy inefficient dwellings in order to reduce the effects of climate change. The case study is a building block owned by Zaragoza City Housing Society, built in the early 90's.

Table 7.5 Commercial and residential projects in Spain

Building	Climate zone, Location	Typology	Type	Scale	Stage
IDOM Madrid Headquarters	Southern-Europe, Madrid, Spain	Office: medium-rise	New-build	5 stories, 15300 m <sup>2</sup>	In use
IDOM Bilbao Headquarters	Southern-Europe, Bilbao, Spain	Office: medium-rise	New-build	5 stories, 14400 m <sup>2</sup>	In use

<b>Rental social housing building</b>	Southern-Europe, Zaragoza, Spain	Residential: apartment block	Renovation	4 stories	In use
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### 7.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

Possible adaptation measures are demonstrated in two buildings of IDOM. Their new Headquarters building in Bilbao is the first building in Spain that has its Study of Climate Change Adaptation according to IDOM. The UKCIP 2003 Methodology has been used to identify the climate change risks, in this case: sea/river level increase and precipitation increase. Hydrometeorology models have been simulated using with the IHACRES software (e.g. IHACRES<sup>224</sup>) to assess adaptation measures.

The second IDOM case, the headquarters in Madrid is the first office building of its size in the Mediterranean climate that incorporates Thermally Activation of the Building Structure (TABS) according to IDOM. The building and the TABS-system are closely monitored and adapted during the use phase. IDOM conducts both active simulation with all HVAC equipment and passive simulation with free-running building.

Buildings are simulated with both of historical and future weather profiles, and METEORONORM software is used for future weather profile projection. IDOM designs the buildings in order to reduce the energy demands and energy consumptions while maintaining the comfort standards with the historic and future weather data. ASHRAE Standard 55 is the main reference for the thermal comfort model and criteria for thermal performance targets – stay in the thermal zone without exceedance of temperature limits.

In terms of the New4Old project, the following adaptation measures have been proposed in the pilot. In actions taken in social housing for renting, passive design strategies are essential due to the limited income of owners. Therefore, the proposed measures will help improve the building’s passive performance and reach a higher thermal comfort, without increasing the economic cost linked to energy consumption.

- Thermal envelope improvements (ETICS wall insulation, replacement of window glazing, roof insulation)
- Solar shading in south façade
- Hybrid solar system for domestic hot water production and electricity production of collective spaces
- Pergola in the central courtyard to improve the micro-climate conditions
- Improvement of the illumination with a passive system
- Prototype of passive solar heating

### 7.3.3.3 How performance improvements were measured

No specific indicators are explicitly identified for IDOM. However, generic EnergyPlus output parameters on thermal comfort can be considered as useful indicators, such as temperature and relative humidity.

<sup>224</sup> Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data (IHACRES), <http://www.toolkit.net.au/tools/IHACRES>

#### **7.3.3.4 Implementation experience of practitioners involved with delivery of the improvements**

In Spain the external temperatures that office buildings are designed to tolerate are usually slightly higher than the current ones, so as to take into account a probable increment in the next few years during the life of a building. The practice in Spain is that the overheating parameters in the regulations are rarely used because the targeted performance values requested by (selected) clients tend to indicate a more ambitious level of efficiency and sustainability. For residential developments, more sophisticated modelling tends not to be used, with a focus on specific measures that can be taken.

Apart from temperature and solar radiation projections, IDOM also uses UKCIP 2003 Methodology to identify the possible climate change risks, e.g. sea level increase and precipitation increase, thereafter hydrometeorology model is built and simulated by using IHACRES software.

IDOM has started to use jEPlus on parametric simulations, and a simulation variable matrix is generated and the economic aspects are added to simulation results as another dimension for further optimization. All of these quantification tools are fairly important, and they are used to improve the design in order to get a better building performance and thermal comfort.

In addition to the climate change phenomenon, the urban heat island phenomenon should also be considered. In the case of Zaragoza, it is particularly worth highlighting the importance of considering adjustment actions to overheating conditions, not only because of climate forecast evolution, but also heat island phenomenon. In this case study, due to the location of the building (in the high density historic quarter), the increase of the temperatures will be even higher than in other less dense areas. In summer, the situation will get even worse due to the prevailing wind.

### **7.4 Findings from the operational experience of selected assessment and reporting schemes**

#### **7.4.1 Assessment and reporting schemes**

In this section, a summary of the main themes and findings to have emerged from a detailed cross-check of relevant criteria from five certification schemes – BREEAM UK, HQE, DGNB, LEED and VERDE (based on SB Tool) - together with associated interviews are presented.

Reference is also made to the criteria of a number of residential-only schemes – Home Performance Index (Ireland), Home Quality Mark (UK), Klimaaktiv (Austria) and Miljo Byggnad (Sweden).

The main observations are grouped into common themes that emerged from the research.

##### **7.4.1.1 A focus on thermal comfort**

All the certification schemes reviewed focus on occupant thermal comfort. They are inconsistent in the methods and standards they refer to, which include CIBSE TM32, EN ISO 7730, EN 15251 and ASHRAE 55.

Thermal comfort criteria are considered by certification scheme operators to be amongst the most commonly complied with criteria as the calculation methods and simulations are familiar to engineers. Their calculation do, however, suppose the use of dynamic simulations which are more complex, and it should be recognised that not all national calculation methods for building energy use are

dynamic (e.g. the UK NCM for homes is based on monthly estimates and gain profiles).

Accordingly, residential schemes in the UK and Sweden offer simplified or 'foundation' compliance routes alongside those that suppose dynamic simulations. In some countries, such as Germany, the simplified overheating assessments with National Calculation Methods do already encourage a focus on the most extreme conditions for a given location.

A further observation was made that in at least one country design teams resist carrying out dynamic simulations because they tend to result in a reduction in the size of HVAC systems. This in turn can reduce consultant fees, even though this optimisation can save clients significantly more money than the cost of the dynamic simulation.

#### **7.4.1.2 Modelling of future climatic conditions**

Only in the recent version of BREEAM UK and in the new UK Home Quality Mark are the effect of future climate projections taken into account. In BREEAM, the criterion refers to the use of 2030 and 2050 weather data files available from the UKCIP. The HQM provides a tool for a simplified assessment of internal temperatures.

In France, HQE will shortly introduce such a requirement, but recognising that the weather data files are difficult to obtain and use, the criterion will adopt a simpler approach by defining stricter tolerances. In France, engineers already model stricter tolerances in a simplified way using data from 2003, when there was a major heat wave which resulted in excess deaths. In Germany there is a similar situation, with a 'hot summer' simulation having to be carried out as part of a simple (steady-state) overheating assessment that is a building permitting requirement.

#### **7.4.1.3 Modelling the impact of green infrastructure**

The VERDE scheme has a number of related criterion that reward modelled savings in the primary energy demand for cooling (kWh/m<sup>2</sup>) associated with green infrastructure. The NCM in Spain allows for inputs to the software that can reflect the shading provided by vegetation on buildings (e.g. green roofs) or in the immediate surroundings of the building (e.g. trees in courtyards or streets).

However, even if input assumptions can be changed in the NCM software, the improvements can still be complex to accurately model and substitute input data that is scientifically robust is not always available (e.g. the shading effect of trees). The extent to which some vegetation, such as trees, would provide the assumed shading upon completion of the building could also be questioned.

### **7.4.2 Progress made by scheme harmonisation initiatives**

#### **7.4.2.1 Common Metrics pilot phase 1, Sustainable Building Alliance**

The Sustainable Building Alliance's initial set of indicators (the 'Common Metrics') included one indicator relevant to MO B5 – thermal comfort. The unit of measurement is defined as the summer % time out of range of a defined maximum and minimum temperature. However, no reference temperature is specified.

The calculation shall be made using a building simulation carried out according to EN 15251, EN 12831, ISO 13972 or ISO 13791. Specifications for in situ measurement shall be according to ISO 7726.

#### **7.4.2.2 CESBA Common European Sustainable Building Assessment (New public buildings v1.1)**

The CESBA assessment scheme includes one criterion on thermal comfort in its v1.1 indicator catalogue. The criterion refers to proof being provided of the summer fitness of the building using static or dynamic methods. Dynamic methods are suggested for naturally ventilated buildings with a glazed area of greater than 35%.

Reference standards are the Passive House Planning Package (PHPP), EN ISO 7730 (where active cooling is used) or national requirements. The criteria specify that the interior temperature shall not be higher than 26 °C for more than 5-10% of the hours in a given year where there is natural ventilation and 3% where there is active cooling.

## 7.5 Identification and screening of potential performance indicators

### 7.5.1 Long list of macro-objective 5 direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>5.1 Interior resilience (thermal comfort and additional cooling energy)</b>							
<b>Temperature</b>	°C	B1-7: Use	Concept design Technical design	Operative temperature Upper limit temperature - Discomfort temperature - Extreme temperature	Dynamic modeling using future weather data (e.g. UKCP09) or representative weather data	Ability to use future weather data (either availability of reliable data or ability to perform calculations using this data)	FS CC
<b>Overheating hours / Overheating risks (rate)</b>	[h] or [%]	B1-7: Use	Concept design Technical design	-	Dynamic modeling using future weather data (e.g. UKCP09 <small>Error! Bookmark not defined.</small> ) or representative weather data		FS AR CC
<b>Comfort levels</b>	PMV-PPD (Predicted Mean Vote - Predicted Percentage of Dissatisfied)	B1-7: Use	Concept design Technical design	-	ISO 7730/15251 ASHRAE STD 55		AR CC



<b>Degree hour</b>	[°C*h]	B1-7: Use	Concept design Technical design	-	Product of temperature and overheating hours		FS
<b>5.2 Exterior resilience (microclimate moderation)</b>							
<b>Shading of the building</b>	Cooling energy saved (kWh/m <sup>2</sup> )	B1-7: Use	Concept design Technical design	Shading of the ground, facades and roofs	Assumptions/input data in NCM or dynamic simulation model	-	AR CC
<b>Green Space Factor</b>	Sum of weighted areas	B1-7: Use	Concept design Technical design	All spaces and building surfaces, weighted by green cover	Methodologies developed for city planning/permitting		FS CC

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

### 7.5.2 Long list of macro-objective 5 supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>5.1 Interior resilience</b>							
<b>Relative humidity</b>	%	B1-7: Use	In-use	See 'macro-objective 4 healthy and comfortable spaces'			FS
<b>Flow rate</b>	m <sup>3</sup> /h	B1-7: Use	In-use				FS
<b>5.2 Exterior resilience</b>							
<b>Green points</b>	Sum of green	B1-7: Use	Concept design	All spaces and building	Methodologies	-	FS

	features		Technical design	surfaces	developed for city planning/permitting		
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*Key to sources:* FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

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## **8. Macro-objective 6: Optimised life cycle cost and value**

### **8.1 Defining the macro-objective's scope and focus**

#### **8.1.1 Policy and technical background to selection of the macro-objective**

##### **8.1.1.1 Development of a common European methodology for Life Cycle Costing (LCC) in construction**

The Commission's interest in supporting Life Cycle Costing as an approach can be traced back to the Communication '*The Competitiveness of the Construction Industry*' COM (97)539. This identified that one of the key ways of improving competitiveness was considered to be the implementation of life cycle cost tools and criteria in all key phases of the construction process.

Some years later, the Communication COM(2005)718 on a *thematic strategy for the urban environment* outlined the need to develop a common methodology at European level for evaluating the overall sustainability performance of building and construction, including life cycle costing <sup>225</sup>.

Following on from this, in 2006, the European Commission appointed the UK consultants Davis Langdon to develop a common European methodology for Life Cycle Costing (LCC) in construction. The scope of the study was to provide an analysis and evaluation of the different national approaches to LCC, as well as elaborating an approach to the estimation of Life Cycle Costs which could be of added value at EU level. The work was to take into account the existing international standard ISO 15686.

Although a little dated now, the findings and outcomes from the Davis Langdon work are analysed as a field study Section 8.3 of this working paper.

##### **8.1.1.2 Framework for calculating cost-optimal levels of minimum energy performance requirements for buildings**

Each member state is required to calibrate their minimum energy performance requirements for buildings against what is termed the 'cost-optimal' performance. The cost-optimal performance is calculated following a simplified LCC methodology as described in Commission Delegated Regulation No 244/2012 <sup>226</sup>.

Member States are required to ensure that, for different building types, any gap between their national minimum requirements and the cost-optimal level is reduced by the time of their next review and by the latest 2015-6. The gap shall in general not deviate by more than 15% from the cost-optimal level.

The cost optimal methodology lays down a minimum set of variables that influence a buildings energy use as well as the factors and assumptions to be included within a financial appraisal. For public buildings, Regulation No 244/2012 stipulates a 30-year time period for the appraisal. Although the discount rate(s) to be used is not stipulated, reference is made to the use of a societal rate used in Commission Impact Assessments of 4% and a higher rate, representing a purely commercial, short-term approach to the valuation of investments.

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<sup>225</sup> COM(2004)60 Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, *Towards a thematic strategy on the urban environment*

<sup>226</sup> Commission Delegated Regulation No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements

### **8.1.1.3 Development of a common European methodology for Life Cycle Costing (LCC) in public procurement**

The Communication on a strategy for the sustainable competitiveness of the construction sector and its enterprises, COM(2012)433 stated that the Commission will support the development of an EU-wide life cycle cost-benefits model for Green Public Procurement and for sustainable development principles in regional policy. This model is currently under development, but with a broader focus on application to a range of products that may be procured.

### **8.1.2 The intended scope and focus**

The macro-objective is specified as focussing on the '*optimisation of the life cycle cost and value of buildings, inclusive of acquisition, operation, maintenance and disposal*'. The proposed scope is intended to include both the application of Life Cycle Costing (LCC) to buildings, and valuation methods for properties that have a higher environmental performance.

Life Cycle Costing (LCC) is an important tool during the project definition, concept design and detailed design stages. At these stages it can be used to select and optimise the design to achieve the lowest overall cost (and highest residual value if whole life costing is also used) along the life cycle of the asset. In accordance with ISO 15686-5<sup>227</sup>, the calculation may also take into account so-called 'intangible' benefits, which may include factors that influence the users' comfort, amenity and productivity.

The potential for better environmental performance to be reflected in a property's value at the point of carrying out due diligence, development appraisals, property market valuations and mortgage calculations will also be examined.

## **8.2 Cross-cutting scoping and investigation of the macro-objective's implementation**

### **8.2.1 Building permitting and planning requirements**

#### **8.2.1.1 Modelling of 'cost-optimal' levels of performance for new-build office buildings**

In Section 8.1.1.2 the EU cost optimal methodology for comparing minimum energy performance requirements at national level was described. The results of cost optimal modelling at EU level and by member states can provide a useful insight into the potential for LCC to stimulate operational performance improvements for new and renovated buildings.

A comprehensive modelling exercise was carried out for DG ENER by a consortium led by Ecofys. This provides an indication of cost-optimal levels of performance for office buildings across the EU<sup>228</sup>. Geographical climate zones were defined in terms of heating and cooling days and a model was then used to simulate a reference office building to which 189 combinations of building envelope, heating and cooling strategies were applied in each climate zone.

The cost-optimal performance for each variant was calculated based on an investment period of 30 years with discount rates of 2%, 4% and 10% applied. An indicative example of the modelled variation in the cost optimality curve is illustrated by Figure 8.1 and Figure 8.2 show a downward shift in the point of cost optimality as capital costs are predicted to reduce over time.

<sup>227</sup> ISO 15686-5, *Buildings and constructed assets: Service life planning – Part 5: Life Cycle Costing*, 15<sup>th</sup> June 2008

<sup>228</sup> Ecofys Germany et al, *Towards nearly zero energy buildings: Definition of common principles under EPBD*, Report for the European Commission, 14th February 2013.

The results were then segmented into notional performance classes expressed in kWh/m<sup>2</sup>. The modelled results for new-build and renovated office buildings for the four climate zones at 2010 and (projected) 2020 prices are summarised in Table 8.1 and Table 8.2.

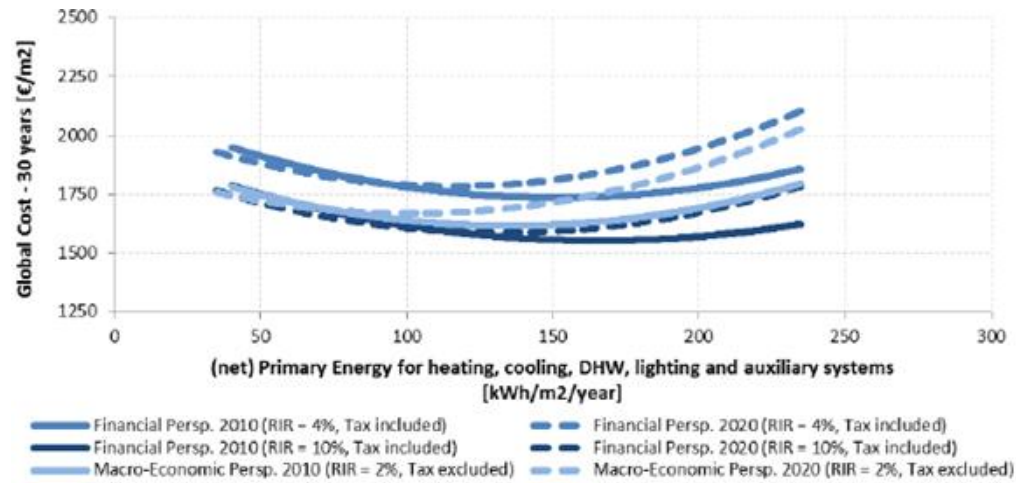


Figure 8.1 Modelled changes in cost optimality curves between 2010 and 2020 for a new office building in Paris, France

Source: Ecofys (2013)

Table 8.1 Cost-optimal modelling results for a new office building in the four EU climate zones

Climate zone (selected city)	2010 results (kWh/m <sup>2</sup> )		2020 Cost-optimal performance (kWh/m <sup>2</sup> )
	Cost-optimal performance	Performance class for top 20% of the building variants	
Catania	120	30 - 45	80
Paris	170	30 - 45	100
Budapest	160	45 - 60	90
Stockholm	160	60 - 75	100

Source: Ecofys (2013)

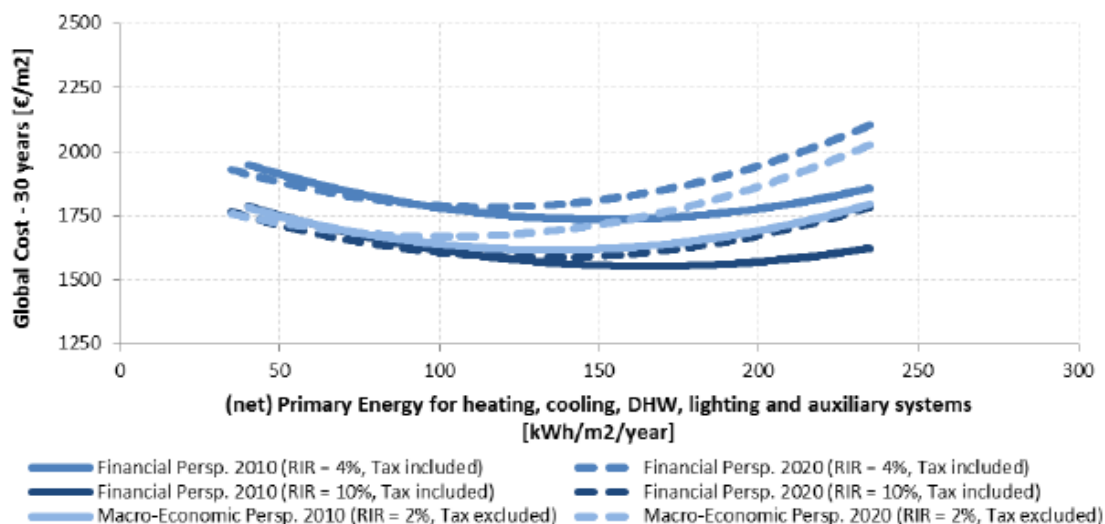


Figure 8.2 Modelled changes in cost optimality curves between 2010 and 2020 for a new office building in Paris, France

Source: Ecofys (2013)

Table 8.2 Cost-optimal modelling results for the renovation of an existing office building stock in the four EU climate zones

Climate zone (selected city)	2010 Cost-optimal performance (kWh/m <sup>2</sup> )	2020 Cost-optimal performance (kWh/m <sup>2</sup> )
Catania	120	90
Paris	170	100
Budapest	160	110
Stockholm	170	80

Source: Ecofys (2013)

The Ecofys findings can be cross-checked with the results of cost-optimal modelling in Member States. Cost optimality comparisons for the four main climate zones of the EU are summarised in Table 8.3 below. Data for the same countries analysed in the Ecofys study could not be compiled because of variations in the reporting by Member States.

The data shows that the variation between the current minimum national requirements and the cost-optimal can be significant. It also illustrates the range of different assumptions that can be used, which can in turn have a significant effect on what would be defined as a cost optimal performance level.

Table 8.3 Example outputs from cost-optimal reporting by Member States

Country	Office building type	Current minimum requirement (kWh/m <sup>2</sup> )	Cost-optimal level (kWh/m <sup>2</sup> )	Variation from the cost-optimal level calculated	Financial assumptions (term and discount rate)
Spain	New-build	49 - 97.3	46.8 - 103.5	-6.0 to +41.4%	20 year term at 7%
	Renovation	52.1 - 85.4	42.7 - 103.0	-16.0 to +77.0%	
UK	New-build	87 - 155	89 - 163	-4%	20 year term at 3.5%
	Renovation	-	-	-	
Hungary	New-build	101	84	+20.2%	20 year term at 5.0%
	Renovation	199 - 256	156 - 227	+27.6% to +12.8%	
Denmark	New-build	32.5 - 103.0	-	+31.2%	20 year term at 3.0%
	Renovation	113.2 - 231.9	-	-6.6% to +3.7%	
Finland	New-build	152 - 161	130.0 - 160.0	+3.9 to +12.6%	20 year term at 6.0%
	Renovation	136	122	+11%	

Source: Member State reports submitted to DG ENV as of 2013, see: [http://ec.europa.eu/energy/efficiency/buildings/implementation\\_en.htm](http://ec.europa.eu/energy/efficiency/buildings/implementation_en.htm)

### 8.2.2 Private and public sector building practices

In this Section, a focus will be placed on initiatives that have sought to establish the link between the environmental performance of properties and their market value. To put this in context, the Royal Institute of Chartered Surveyors (RICS) describes market value as:

*'the estimated amount for which a property should exchange on the date of valuation between a willing buyer and a willing seller in an arm's-length transaction after proper marketing wherein the parties had acted knowledgeably, prudently and without compulsion'*

Four broad areas of activity have been identified in the international and EU property market:

1. Attempts to identify or establish a link between a building's environmental performance and its market value;
2. The integration of environmental performance and risks into the valuation process for properties;
3. Better accounting for environmental performance and risk factors in investor reporting and due diligence processes (i.e. *reasonable endeavours to identify risks associated with an investment*);

4. The consideration of the environmental performance of properties when making home mortgage calculations, which may in turn have an influence of market values.

These areas of activity can be seen as part of a broader move to integrate consideration of environmental performance, as well as related health and quality aspects, into standard operating practices in the property market.

### **8.2.2.1 Establishing a link between building environmental performance and increased market value**

A number of studies and industry initiatives have sought to establish a link between the improved environmental performance of buildings and an uplift in property values, with inconclusive or partial results. RICS, however, highlights the risk of making generalisations about increases in value. This risk is based on evidence from a number of commonly cited studies that analysed the US property market<sup>229</sup> as well as factors relating to the supply of property in a market, such as lease length and rent free periods that can affect findings<sup>230</sup>. The limited work to analyse residential property market was also noted.

One of the main challenges cited is that property valuation is to a great extent reliant on the judgement of valuers and the prevailing market conditions<sup>231</sup>. As Rodrigues et al (2012) further emphasise, it also depends on how improved environmental performance is defined, with the UK Sustainable Property Index cited as an example of a relatively crude metric. Moreover, the influences of prevailing property market conditions may skew any recent (post 2007) statistics because of risk aversion.

A common focus for studies is the influence of improved energy performance, or the status of poorly performing properties. Brounen and Kok (2010)<sup>232</sup> and Kok and Jennen (2012)<sup>233</sup> examine the influence of Energy Performance Certificates in the property market in the Netherlands, where they were introduced ahead of the EU EPBD. For both commercial and residential properties, they found a significant differentiation in rental prices and selling prices respectively.

RICS (2014) cites a range of other sources of evidence from the UK and German residential markets that claim a positive correlation between energy labelling and selling prices. Anticipated regulation of poorly performing properties can also have an impact on future property values and liabilities, as can be seen in the case of EPC F or G rated rental properties in the UK<sup>234</sup>.

### **8.2.2.2 Integrating environmental performance and risk into property valuation methodologies**

A new focus of attention has been the potential to integrate environmental performance and risk factors into property appraisal and valuation methodologies used by surveyors and clients. This could have a wider and more fundamental influence, because it would address the underlying assumptions made when attributing value to different features of a property, as well as potential future risks to occupancy rates and rental levels, and therefore yields. As we will go on to discuss, such an approach can also influence the perception of opportunities and risks associated with investments or borrowers.

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<sup>229</sup> RICS Research, *Measuring green value: an international perspective*, September 2014

<sup>230</sup> RICS Research, *Supply, demand and the value of green buildings*, March 2012

<sup>231</sup> Rodrigues.L, Garratt.T and Ebbs.N, *Energy Conversion and Management*, 63 (2012) 203–207

<sup>232</sup> Brounen D and Kok N. *Research report on the economics of EU energy labels in the housing market*. London: Erasmus University and Maastricht University; 2010.

<sup>233</sup> Kok.N and Jennen.M, The influence of energy labels and accessibility on office rents, *Energy Policy* 46 (2012) 489–497

<sup>234</sup> Brown, C. Prepare for applicants who take rejection well, *Planning Resource*, UK, 11<sup>th</sup> March 2016



An early example is the Sustainable Property Appraisal project carried out by the University of Kingston in the UK <sup>235</sup>. The project developed and piloted an appraisal tool in conjunction with a range of industry stakeholders. The tool comprised a series of parameters for estimating the impact on a properties worth (value). The main output was a 'future proofing' property questionnaire which generates a property rating. This rating is then linked to parameters within the tool, that indicate the potential influence on value over time.

Lorenz and Lützkendorf (2012) <sup>236</sup> make reference to international requirements for banks (under the so-called Basel II rules), as well as examples from Germany, Austria and Switzerland, to create risk ratings for property assets and property borrowers. They identify three broad types of rating that underpin the market:

1. Combined ratings of a borrower and the property;
2. Ratings of a property only, apart from the credit rating of the borrower;
3. Determination of a bank's potential loss in the event of a loan default.

The roles of borrower and property ratings, and their interrelationship with the process of providing credit, are illustrated in Figure 8.3.

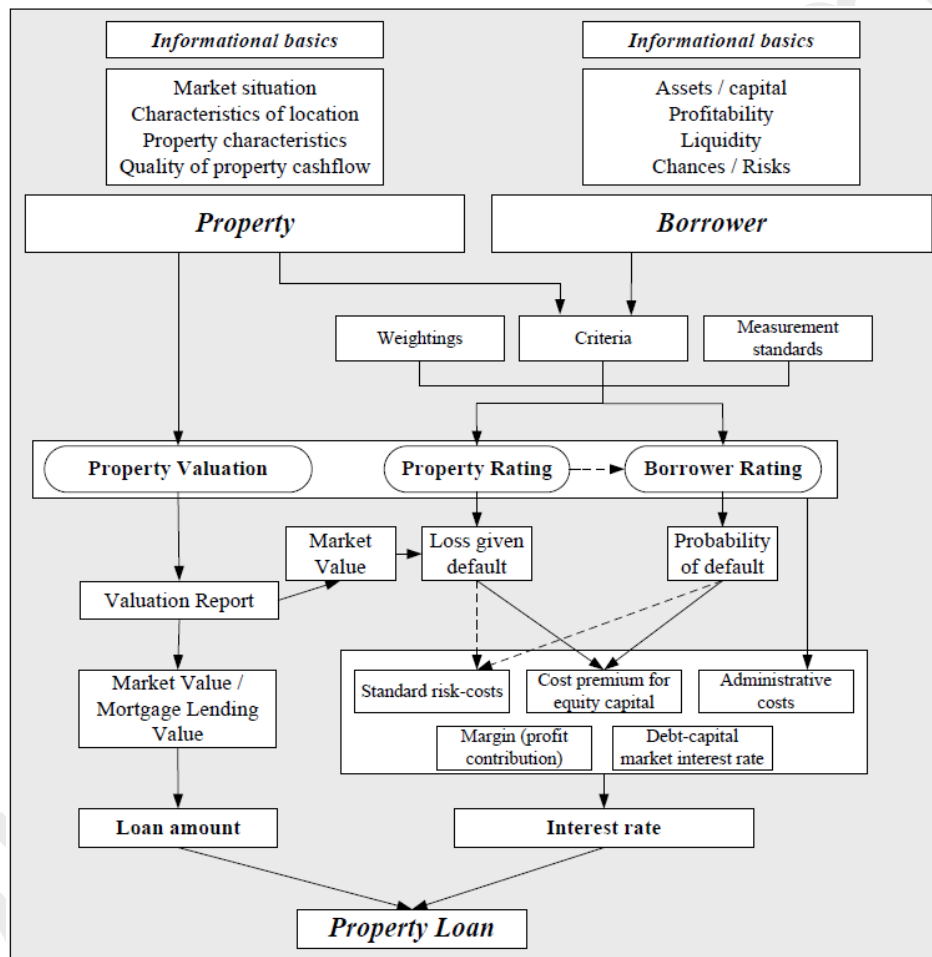


Figure 8.3 Determinants of financing conditions for properties under Basel II

Source: Lützkendorf.T and Lorenz.D (2012)

<sup>235</sup> Ellison.L and Sayce.S (2006) *The Sustainable Property Appraisal project*, Kingston University

<sup>236</sup> Lützkendorf.T and Lorenz.D (2012) *Integrating sustainability issues into property risk assessment – an approach to communicate the benefits of sustainable buildings*, University of Karlsruhe (TH)

The European Group of Valuers Associations (TEGoVA) property rating system is referred to in a number of studies on this subject<sup>237</sup>. This system is understood to be widely used across the EU and lays down the factors to be taken into account when making a property rating. TEGoVA highlights the use of ratings for the risk analysis of property portfolios and investment decisions.

Within the TEGoVA valuation class criteria for different building types, it is possible to identify factors that may be influenced by an environmentally improved building. These could include future costs and liabilities arising from, for example, *changes in legislation, 'acts of god', letting prospects, structural condition and adaptability*.

Some of these criteria go beyond a simple focus on operational performance, and relate to the long-term stability of the investment, both in terms of the building and the market – direct and indirect points of connection between environmental performance and property financing and risk analysis.

The SB Alliance and UNEP similarly identify a listing of aspects which are recommended to be factored into an appraisal or risk rating in order to broaden the potential to capture the value of a 'green' building<sup>238 239</sup>.

### **8.2.2.3 Integrating environmental performance and risk into investor reporting and due diligence processes**

Due diligence procedures prompted by Corporate Social Responsibility (CSR) and/or Socially Responsible Investment (SRI) policies are increasingly used by higher profile investors in order to manage reputational risk. Due diligence procedures are used to ensure that reasonable endeavours are taken to identify risks associated with an investment.

In Working Paper 1, five property investor reporting tools were analysed. Of these five, the reporting tool GRESB under *'risks and opportunities'* asks participants to report on the extent to which they have incorporated environmental, quality and life cycle cost factors into due diligence processes for property acquisitions. The GRESB list used could form the basis for a checklist for investors.

### **8.2.2.4 Taking into account environmental performance in mortgage calculations**

In Section 8.2.3.2 the risk rating attributed to borrowers was highlighted. With the introduction of EPCs residential mortgages have become a focus for attention, with a number of studies in the UK having looked at the factors that can be influenced in mortgage calculations – with energy costs having been, or are in the process of being studied<sup>240 241</sup>. The basic premise is that savings in home energy cost savings can be capitalized and therefore have a value. This value can then be taken into account when assessing the affordability of repayments or to securitise more lending.

## **8.2.3 Collaborative EU projects**

A number of EU funded studies have sought to explore how reduced life cycle energy costs can be factored into investment and value appraisal techniques.

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<sup>237</sup> TEGoVA, *European property and market rating: A valuer's guide*, October 2003

<sup>238</sup> Sustainable Building Alliance (2015) *Sustainability thresholds generating value*,

<sup>239</sup> UNEP, *Sustainability metrics – translation and impact on property investment and management*, Report of the Property Working Group of the UNEP Finance Initiative, May 2014

<sup>240</sup> UK GBC and University College London, *The role of energy bill modelling in mortgage affordability calculations*, August 2015

<sup>241</sup> BRE, *BRE conducts study on green mortgage lending*, 30<sup>th</sup> November 2015

These include ImmoValue<sup>242</sup>, Revalue<sup>243</sup> and Renovalue<sup>244</sup>. The ImmoValue project is analysed further as a field study in Section 8.3.

From the findings to date, some key points emerge:

- Data availability and quality related to EPCs and LCC calculations appears to be an issue.
- To achieve wider integration of energy cost savings into market valuations, valuers need reliable databases on reference buildings ('comparables') including not only data on the location, rent level and building equipment, but also on energy performance.
- Discounted cash flows which use LCC calculations as their basis are in theory directly useable by quantity surveyors and valuers, but may need to be disaggregated in order to make them useful *e.g. by identifying the costs that are attributed to tenants*.
- Valuers require training to enable them to be capable of interpreting energy benchmarks, the results of LCCA and other technical characteristics of the building in a correct way.

The issue of uncertainty relating to valuations is also addressed by bodies such as the SB Alliance (2015)<sup>238</sup>. They recommend the use of more detailed uncertainty modelling, using techniques such as Monte Carlo simulations.

## 8.2.4 Standards and harmonisation initiatives

### 8.2.4.1 Life Cycle Costing

The Common LCC Methodology developed by Davis Langdon (2007) for the European Commission<sup>245</sup> and the standard ISO 15686-5<sup>246</sup> serve as common references for the building industry. CEN/TC 350 has also developed the standard EN 15643-4<sup>247</sup> which also now serves as a reference framework for the economic assessment of buildings, supported by the calculation method EN 16627<sup>248</sup>. The structure of the two EN standards are aligned with the life cycle stages and modules which form the basis for EN 15804 and EN 15978.

According to the ISO standard assessment of LCC can be made at a benchmark level for a whole building or at a detailed level, with reference to elements and components of a building. The scope of the ISO standard is illustrated in Figure 8.4. The EN standard makes reference to '*building-integrated technical systems*' and '*building-related furniture, fixtures and fittings*'. A number of costing methodologies are referred to, including real costs, nominal costs and discounted costs.

### 8.2.4.2 Whole life costing and financial value

Both the ISO and EN standards encompass LCC and Whole Life Costing (WLC). The EN standards refer to the latter as the assessment of financial value as well as cost – requiring estimates of market-related revenue (income) streams. This

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<sup>242</sup> ImmoValue, *Improving the market impact of energy certification*, <http://immoval.e-sieben.at/>

<sup>243</sup> Revalue, *Recognising energy efficiency value in residential buildings*, <http://revalue-project.eu/>

<sup>244</sup> Renovalue, <http://renovalue.eu/>

<sup>245</sup> Davis Langdon Management Consulting (2007) *Final Guidance Life cycle costing (LCC) as a contribution to sustainable construction Guidance on the use of the LCC Methodology and its application in public procurement. Towards a common European methodology for Life Cycle Costing (LCC) – Guidance Document*. European Commission.

<sup>246</sup> ISO (2008) *ISO 15686-5 Buildings and constructed assets – service life planning – Part 5: Life Cycle Costing*.

<sup>247</sup> CEN, EN 15643-4: *Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance*, January 2012

<sup>248</sup> CEN, EN 16627: *Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods*, June 2015

includes provision for the assessment of value stability and performance over time.

A number of different financial appraisal methods are referred to, reflecting the range of methods that may be used by investors – simple pay back, savings to investment ratio, Internal Rate of Return (IRR) and Net Present Value (NPV).

The EN standards make reference to consideration of '*consequential economic aspects*' that may relate to the added value of risks associated with a property investment. Within the calculation of whole life costs, the ISO standard makes reference to the inclusion of '*intangibles*', which can include value aspects of a user's 'comfort, amenity and efficiency'.

Life-cycle cost (LCC)			
<b>Construction</b>		Y/N	
Professional fees	<input type="checkbox"/>		Project design and engineering, statutory consents
Temporary works	<input type="checkbox"/>		Site clearance, etc.
Construction of asset	<input type="checkbox"/>		Including Infrastructure, fixtures, fitting-out, commissioning, valuation and handover
Initial adaptation or refurbishment of asset	<input type="checkbox"/>		Including Infrastructure, fixtures, fitting-out, commissioning, valuation and handover
Taxes	<input type="checkbox"/>		Taxes on construction goods and services (e.g. VAT)
Other	<input type="checkbox"/>		Project contingencies
<b>Operation</b>			
Rent	<input type="checkbox"/>		
Insurance	<input type="checkbox"/>		Building owner and/or occupiers
Cyclical regulatory costs	<input type="checkbox"/>		Fire, access inspections
Utilities	<input type="checkbox"/>		Including fuel for heating, cooling, power, lighting, water and sewerage costs
Taxes	<input type="checkbox"/>		Rates, local charges, environmental taxes
Other	<input type="checkbox"/>		Allowance for future compliance with regulatory changes
<b>Maintenance</b>			
Maintenance management	<input type="checkbox"/>		Cyclical inspections, design of works, management of planned service contracts
Adaptation or refurbishment of asset in use	<input type="checkbox"/>		Including Infrastructure, fitting-out, commissioning, validation and handover
Repairs and replacement of minor components/small areas	<input type="checkbox"/>		Defined by value, size of area, contract terms
Replacement of major systems and components	<input type="checkbox"/>		Including associated design and project management
Cleaning	<input type="checkbox"/>		Including regular cyclical cleaning and periodic specific cleaning
Grounds maintenance	<input type="checkbox"/>		Within defined site area
Redecoration	<input type="checkbox"/>		Including regular, periodic and specific decoration
Taxes	<input type="checkbox"/>		Taxes on maintenance goods and services
Other	<input type="checkbox"/>		
<b>End-of-life</b>			
Disposal inspections	<input type="checkbox"/>		Final condition inspections
Disposal and demolition	<input type="checkbox"/>		Including decommissioning, disposal of materials and site clean-up
Reinstatement to meet contractual requirements	<input type="checkbox"/>		On condition criteria for end of lease
Taxes	<input type="checkbox"/>		Taxes on goods and services
Other	<input type="checkbox"/>		

Figure 8.4 Typical scope of costs to be selected for LCC analysis

Source: ISO (2008)

### 8.2.4.3 Data quality

A challenge identified in this Chapter is the availability and quality of data on the cost of building elements and components. Generic cost yardsticks may be published at national level according to conventions established by sectoral organisations (e.g. the RICS Building Cost Information Service in the UK). The

ISO 15686 standard series includes part 9, which addresses reference service life data. EN 16627 makes reference to data quality, identifying that:

- data should be as current as possible;
- data shall have been checked for plausibility;
- the technological coverage shall reflect the physical reality for the declared product or product group;
- the geographical coverage shall be representative of the region where the production is located.

The carrying out of a sensitivity analysis is recommended, and data quality shall be reported.

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## **8.3 Findings from investigation of the selected field study clusters**

The macro-objective B6 field studies consist of four clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- ALTO offices – new-build and renovation (France and Luxembourg): Life Cycle Costing;
- LCC-Data: Pilot of Life Cycle Costing methodologies (five EU countries);
- IMMO-VALUE: Pilot testing of property valuation methods (three EU countries);

For each cluster, the performance improvements implemented, indicators used and lessons from implementation are briefly summarised.

### **8.3.1 Cluster 1: ALTO offices – new-build and renovation**

#### **8.3.1.1 Background and context to selection of the cluster**

*An overview of this ALTO building cluster is provided in Section 2.4.*

#### **8.3.1.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

LCC analyses were conducted for the CBK II, Euler and Zenora projects according to the BREEAM International 2009 Certification scheme criteria. In the case of CBK II, additional LCC analyses were performed to respond to the DGNB certification criteria.

The performance targeted differs in each certification scheme (BREEAM, DGNB) and the year of registration. Nevertheless, both schemes follow the LCC-standard ISO 15686-5.

The goal of *BREEAM Life Cycle Cost* is to identify and encourage the development of a Life Cycle Cost (LCC) analysis model to improve design, specification and through-life maintenance and operation costs. The BREEAM Life Cycle Cost analysis is done at the early stage of conception and is based on a concept design covering the following stages:

- a. Construction
- b. Operation
- c. Maintenance - including, as a minimum, planned maintenance, replacements and repairs, cleaning, management costs
- d. End of life.

The LCC analysis is done for a life span of 25 or 30 years (as applicable) and 60 years, showing results in real and discounted cash flow terms. At least two of the following issues have been analyzed at a strategic and system level, comparing alternative options:

- Structure
- Envelope
- Services
- Finishings

As a result, in the case of new build and renovated offices, LCC has only been applied at building element level as opposed to building level.

*DGNB Life-cycle costing* is a valuable technique that is used for predicting and assessing the cost performance of constructed assets. In order to determine whether a project meets the client's performance requirements against ISO 15686-Part5, a DGNB LCC analysis has been realised.

In this case, all the costs from project development to construction and handover of the building are defined as acquisition costs. Maintenance and operation costs are determined at net present value over a period of 50 years.

Costs are given as a net value per m<sup>2</sup> of gross floor area. The DGNB scheme provides benchmarking values and awards credits according to these values:

- One credit (minimum score) is awarded if the building achieve a LCC net value < 3.620 [€/m<sup>2</sup> GFA];
- ten credits (maximum score) if LCC net value < 2,000 [€/m<sup>2</sup> GFA].

In the case of CBK II, nine credits were achieved

The evaluation is performed by comparing the building ecological performance data to comparable buildings.

The following selected cost categories are taken into account when calculating building-related life-cycle costs:

1. Selected construction costs
2. Selected occupancy costs
  - a. Selected operation costs (supply and disposal, cleaning, energy consumption, operation, inspection, and maintenance)
  - b. Selected maintenance costs
  - c. Selected dismantling and disposal costs

The following criteria are considered:

Criteria 1: selected supply costs: energy/electricity and water

Criteria 2: sewage disposal

Criteria 3: building cleaning and care

Criteria 4: operation, inspections and maintenance

Criteria 5: repair of building structures

Criteria 6: repairs to technical building equipment

### **8.3.1.3 How performance improvements were measured**

*Potential indicators identified:*

- Net present value [normalized per m<sup>2</sup>]

*Supporting indicators:*

- Building element and component life spans

### **8.3.1.4 Implementation experience of practitioners involved with delivery of the improvements**

The *BREEAM criterion* was used in France for an analysis of the three buildings at the design phase. The indicators and the associated methodology required were not found to be accessible to all the project's actors for a number of reasons:

- The client did not plan for the LCC studies in the contracts;
- The environmental consultant had difficulties to guide the design team in the completion of studies;
- The design team had not carried out an LCC before in the context of a design;
- There was a lack of national databases or common guidelines to support LCC analyses in France.

In practice, the design teams did have the competence to conduct the LCC analyses. For instance, the cost consultants were familiar with cost data and could draw on their experience, while the engineers already possessed data on maintenance costs. The main knowledge gaps identified were linked to the end of life of the building and for all the categories of building elements (structure, envelope, services or finishing).

Regarding *DGNB*, the necessary expertise was not really available within the design team but the methodology was explained in detail. Default values for maintenance and end of life of the building were proposed in the manual. As a result, consultants was able to compile data and finalise the study. In the case of *CBK II*, these default values were effectively used.

In both cases, the scheme provided limited support. *DGNB* was at its pilot version and no tool was available for this criterion. *BREEAM* did not provide any tool or data to carry out LCC studies.

Having a standard LCC tool and supporting cost data available in each country may ensure a possible comparison between projects. Although it is appreciated that this may be difficult because there may be many differences from one Member State to another.

### **8.3.2 Cluster 2: LCC-Data**

#### **8.3.2.1 Background and context to selection of the cluster**

LCC-DATA was a European project (co-funded by the Intelligent Energy Europe (IEE) programme), with an international consortium of partners of six countries (Norway, Czech Republic, Germany, Greece, Austria, Slovenia). Coordinator of the project was the Norwegian research institute SINTEF. The project ended in 2009.

LCC-DATA aimed at easing and extending the use of Life Cycle Costs Analysis (LCCA) in the construction industry. In more practical terms, the project aimed at developing a web-based database for benchmarking buildings' in-use costs (operation, maintenance, management, energy, etc) in order to ease LCC calculations. The majority of the case studies covered in LCC-DATA were office buildings (both new-build and renovations), although a number of residential buildings are included as well.



Table 8.4 Schedule of projects analysed as part of LCC-Data

Building	Climate zone, Location	Typology	Type	Scale	Stage
Vestfold University College	Northern-Europe, Norway	Office: mid-rise	New-build	2 storeys, offices, auditoriums, library	Design
Sogn of Fjordane University College	Northern-Europe, Norway	Office: low-rise	New-build	3 storeys, offices, auditoriums, cafeteria	Design
Elementary school "Vrchlickeho"	Central-Europe, Czech Republic	Office: low-rise	Renovation	Gross area 5.185 m <sup>2</sup> . Main building and gym	In-Use
CRES main office	Southern-Europe, Greece	Office: low-rise	Renovation	2 storeys, offices, reception area, meeting rooms	In-Use
CRES bioclimatic office	Southern-Europe, Greece	Office: low-rise	Renovation	2 storeys. 529 m <sup>2</sup> gross area. office areas, library and small meeting room	In-Use
GSIS – Ministry of Finance and economics	Southern-Europe, Greece	Office: low-rise.	Renovation	4 storeys, 4.800 m <sup>2</sup> per floor. 30.000 m <sup>2</sup> gross area.	In-Use
Os Frana Albrehta and OS Toma Brejca in Kamnik	Southern-Europe, Slovenia	Office:	New-build	Two buildings one with 4.867 m <sup>2</sup> and other with 4.749 m <sup>2</sup> net floor area	Design
Apartment building	Southern-Europe, Slovenia	Residential: Apartment building	New-build	2 wings, 4 storeys and penthouse flat. Garages and wellness center with swimming pool and sauna in the ground floor	Design
Social housing Steletova	Southern-Europe, Slovenia	Residential: apartment building	Renovation	5 storeys, 3.800 m <sup>2</sup> net floor area, 60 flats	In-Use
TECHbase	Central-Europe, Austria	Office: low-rise	Renovation	Rentable floor area of 12.500 m <sup>2</sup> of which 7.500 m <sup>2</sup> is used as office area	In-Use

BRC	Central-Europe, Austria	Office: medium-rise	Renovation	7 storeys. Rentable floor area 5.110 m <sup>2</sup>	In-Use
Mariahilfer Strasse	Central-Europe, Austria	Office	Renovation	7 storeys. Rentable floor area 3.600 m <sup>2</sup> in 6 floors. Shopping mall in the ground floor. Two parking floors underground..	In-Use
Justice_1	Central-Europe, Germany	Office	Renovation	7 buildings. 136.432 m <sup>2</sup> net ground floor	In-Use
Culture_1	Central-Europe, Germany	Offices and museum	Renovation	15 properties. 79.165 m <sup>2</sup> net ground floor	In-Use
School_1	Central-Europe, Germany	Schools	Renovation	9 properties. School and gym buildings. 92.692 m <sup>2</sup> net ground floor	In-Use

### 8.3.2.2 Translation of the macro-objective into actions and improvements by buildings in the cluster

A database for benchmarking life cycle costs of building projects was developed as part of the project. The purpose of this benchmarking exercise is to make LCC analysis more accessible. LCC analysis is often too time-demanding or too complex for the stakeholders (e.g. architects, engineers, large property owners).

The cost classification for this database is based on international cost classification systems (in particular ISO 15686-5 and the common methodology developed by Davis Langdon) and national cost classification systems (such as NS 3454 (Norway), ÖNORM B 181-2 (Austria) and DIN 18960 (Germany)): capital costs (including construction costs and other investment costs), running costs (administration, operation, maintenance, development, cleaning but excluding energy use) and energy costs (heating, cooling, electricity).

LCC-data distinguishes between Level 1 and Level 2 calculations:

- Level 1 Life Cycle Costing uses statistical data such as the generic database developed within this project. Level 1 calculations are most relevant in the planning phase.
- Level 2 Life Cycle Costing uses detailed data, project-specific; according to national rules. In case specific data is not available, level 1 data can be used as a proxy. Level 2 calculations are most relevant for (preliminary or technical) design phase.

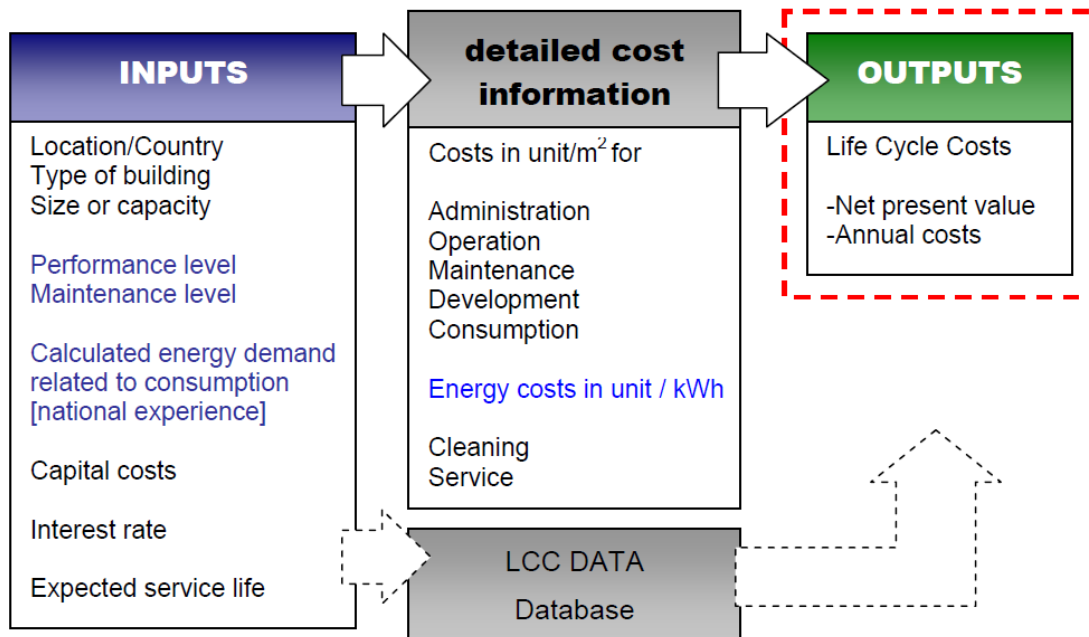


Figure 8.5 Overview of LCC-Data approach

Source: LCC-Data (2009)

The project concludes that as for the kind of building and the size, the developer may rely on level 1 analysis as a tool for decision making. However, for more detailed decisions, e.g. choosing the heating option, the level 2 analysis is more practical.

Level 2 LCC calculations of a building are tailored and depend on the detailed data for building elements, life time and maintenance needs/requirements. Available data at this stage is more detailed and project-specific. Hence, the accuracy of estimates improves and enables investors to choose between specific development activities. Nevertheless, data about running costs are often taken from level 1 LCC calculations, since more reliable information is rarely available.

In general, the aim of the database created is to generate key-figures to be used in the level 1 analysis in the early design stage, thus helping to prevent time-consuming activities, and to be comparable to the outcome of detailed level 2 analysis. In that case, only a little input data would be required and the calculation of running costs over the lifetime are also easy to perform.

### 8.3.2.3 How performance improvements were measured

The key indicators identified were:

- Annual costs [local currency per year or normalized per m<sup>2</sup> per year]
- Total Net Present Cost<sup>249</sup> [local currency or local currency per m<sup>2</sup>]

Key performance indicators can be the costs in different categories, as well as total cost (for instance Net Present Value). More detailed cost categories give a better possibility to look into all steps in the supply chain, and to carry out more thorough analysis to identify and quantify costs in the different processes. [LCC-DATA, 2009]

#### Annual costs

The annual costs include:

<sup>249</sup> Net Present Value is the commonly used term, however, to avoid confusion with the aspect “value” of macro-objective B6, the term “Net Present Cost” is used.

- Running costs comprising administration, operating, maintenance, development and cleaning.
- Energy costs: Heating, cooling and electricity.

Capital costs may sometimes be included as annual costs when they are depreciated during the lifespan of the building. Most of the case studies included capital costs as a one-off cost at the beginning of the project. Capital costs are often missing, especially in cases of buildings older than 5 years. In addition, average construction costs per m<sup>2</sup> and per building use are often available at national statistical level.

Maintenance costs are often disregarded. Systematic maintenance would decrease reactive maintenance and avoid any material or construction failures. Development costs are sometimes included in the capital or maintenance costs.

LCC can be used to calculate the trade-off or cross-link with energy performance and (operational) GHG emissions (in combination with energy simulation tools). In a number of cases (for instance, Slovenia and Austria), LCC was also used in combination with operational energy use simulations to measure the costs and benefits of reducing CO<sub>2</sub> emissions (kgCO<sub>2</sub>e/m<sup>2</sup>/yr) and primary energy consumption (kWh/m<sup>2</sup>/yr)

#### *Net Present Costs*

The Net Present Value or Costs is a commonly used economic parameter that compares the amount invested today to the present value of the future cash receipts from the investment.

The NPV calculation can be used to evaluate investments aimed at improving the energy behaviour of the building. Although sometimes, the most economical viable investment may not be the one having the largest impact on CO<sub>2</sub> emissions and energy and water savings. This is illustrated by the Slovenian case study.

#### **8.3.2.4 Implementation experience of practitioners involved with delivery of the improvements**

In general, the case studies do not present enough information to make them fully comparable, e.g. because of the different LCC standards used, the building life spans assumed. Moreover, the goal of the project was to compare *within each case* the level 1 and level 2 calculations.

The difference in the results of the calculations between level 1 and 2 varies. The range varies per categories and countries: e. g. maintenance costs varied by as much as 39% in one case because level 2 data assumed greater financial outlay. But in general, the level 1 calculation with the LCC-DATA database seems to be useful and validated by comparison with level 2 data.

For all further LCC calculations, it is important to enlarge the amount of data in the databases in order to obtain more reliable figures for the most important cost centres.

Another point of attention is the fact that the calculations were performed by experts in the field who are familiar and experienced in these types of calculations. Based on the information that is publicly available, it is difficult to conclude whether LCC-DATA succeeded in making LCC calculations more accessible to other stakeholders. In other words, it is unsure if it facilitated the implementation of LCC analyses in more common building practices.

The LCC analyses conducted for the case studies drew attention to the following learning points:

- Comparability: the need for consistency in assumptions and data entries so as to be able to compare scenarios and building projects;

- Data requirements: the desired end-use for the LCC calculation results determine the level of accuracy of the data. See also discussion on the level 1 and level 2 calculations;
- Reliability of the benchmarks derived from the database: the number and quality of entries in the database will influence the reliability

The national frameworks regarding LCC calculations are very different between the chosen countries. While some countries, such as Norway, have a standard in place; other countries do not have any directive, as the Czech Republic. Since the country comparison was not the main goal of the project, the presented results per country do not allow to draw cultural-wise conclusions. Only the Austrian partner compared the LCC database to their national available benchmark.

Finally, the LCC-DATA project was concluded in 2009. The project conclusions would need to be further cross-checked with the recent evolutions in LCC calculations and practices.

### 8.3.3 Cluster 3: IMMO-VALUE

#### 8.3.3.1 Background and context to selection of the cluster

ImmoValue (*property valuation, linking energy efficiency of buildings and property valuation practice*) is an Intelligent Energy Europe (IEE) co-funded project<sup>250</sup>, with international consortium of six partners from four countries (Romania, Austria, Germany and Sweden). Coordinator was KPMG Financial Advisory Services GmbH (Austria). The project started in 01/09/2008 and ended in 30/04/2010

The project aimed at integrating energy efficiency and partly other sustainability aspects into property valuation standards. In a first step, the project team developed a solid "modified" valuation approaches. In a second step, the approaches have been checked through a comprehensive expert reviewing process with direct involvement of the relevant association for property valuation, the Royal Institute of Chartered Surveyors (RICS) or The European Group of Valuers Association (TEGoVA). In the third step, the newly developed standards for property valuation have been disseminated to the market.

Table 8.5 Schedule of projects analysed as part of IMMO-VALUE

Building	Climate zone, Location	Typology	Type	Scale	Stage
<b>Modified Income approach</b>					
Vienna Offices building	Central-Europe, Austria	Office: mid-rise	Renovation	GFA <sup>251</sup> of approx. 30,000 m <sup>2</sup> GLA of 21,421 m <sup>2</sup> .	In-Use

<sup>250</sup> European Commission (2016) *IMMOVALUE* [online], available at: <https://ec.europa.eu/energy/intelligent/projects/en/projects/immovalue> [20/5/2016]

<sup>251</sup> Gross Floor Area

Tenement in Graz	Central-Europe, Austria	Residential: apartment building	Renovation	GFA of approx. 3,000 m <sup>2</sup> GLA of 2,000 m <sup>2</sup> .	In-Use
Condominium in Bad Häring/Kufstein	Central-Europe, Austria	Residential / office	Renovation	GLA <sup>252</sup> of 92.53 m <sup>2</sup> .	In-Use
Condominium in Feldkirch-Toster	Central-Europe, Austria	Residential: apartment building	Renovation	GLA of 94.58 m <sup>2</sup> .	In-Use
Commercial Unit in Vienna – Freehold Interest	Central-Europe, Austria	Residential: apartment building	Renovation	GLA of 59.78 m <sup>2</sup> .	In-Use
Community Center in the Ruhr Area	Central-Europe, Germany	Mix residential / office	Renovation	GFA of approx. 12,908 m <sup>2</sup> and GLA of 10,757 m <sup>2</sup> .	In-Use
Multi-family Building in the Rhine-Main Area	Central-Europe, Germany	Residential: apartment building	Renovation	GFA of approx. 6,120 m <sup>2</sup> and GLA of 4,095 m <sup>2</sup> .	In-Use
Office Building in the Oresund-Region	Northern-Europe, Sweden	Office	Renovation	GFA of approx. 23,014 m <sup>2</sup> and GLA of 16,440 m <sup>2</sup> .	In-Use
Care Retirement Home in the Ruhr Area	Central-Europe, Germany	Residential	Renovation	GFA of approx. 5,750 m <sup>2</sup> and GLA of 4,286 m <sup>2</sup> .	In-Use
<b>Modified Sales Comparison Approach</b>					
Residential property in Iasi	Southern-Europe, Romania	Residential: apartment building	Renovation	GLA of 234.26 m <sup>2</sup> .	In-Use
<b>Modified Cost Approach</b>					
Single-family House in St. Christophen	Central-Europe, Austria	Residential: single-family house	Renovation	GFA main building 230 m <sup>2</sup> .	In-Use
Single-family House in Nußdorf am Attersee	Central-Europe, Austria	Residential: single-family house	Renovation	GFA main building 301.63 m <sup>2</sup> .	In-Use
Single-family House in St. Andrä i.L	Central-Europe, Austria	Residential: single-family house	Renovation	GFA main building 235 m <sup>2</sup> .	In-Use
Condominium in Braunau	Central-Europe, Austria	Residential:	Renovation	Finished in 1996, GLA 90.08 m <sup>2</sup> .	In-Use

<sup>252</sup> Gross Leasable Area

### **8.3.3.2 Translation of the macro-objective into actions and improvements by buildings in the cluster**

IMMOVALUE contributed in bridging the gap between theoretical importance and the practical application in integrating energy efficiency, LCC and other sustainability issues into property valuation by offering modified methodologies which are based on standard valuation approaches but reflect energy efficiency and LCC in a more transparent and quantitative way.

The project developed three methodologies for the calculation of the market value of a building, integrating LCC and energy efficiency costs for developed and opaque markets. The new methodologies are based on three common methods to calculate market value: income related, sales comparison and cost approaches.

#### *Income related approach,*

The project developed a score-card called WAPEC (Weighted Adjustment for Valuation Parameter Effecting Characteristics). The WAPEC-model gives guidance for the valuer to process his thoughts regarding the integration of energy efficiency and other sustainability issues into his valuation in a structured and transparent way. The indication of to which degree energy efficiency and/or other related issues affect the property markets is expressed through the so-called "Market Adjustment Rate" (MAR). The valuer can use the MAR to describe the quantity of the market's attention and willingness to pay for energy-efficient buildings.

#### *Sales comparison approach*

This is based on the idea that the Energy Saving Potential (ESP) of a building represents a feature to be taken into consideration in valuation procedures. The ESP is the difference between the annual energy demand and the annual reference energy demand of the building. Both pieces of information can be extracted from the EPC. The MAR parameter is then applied to the ESP. Using statistical analysis tools, the valuer can analyse the influence of each factor and estimate the market value of the properties. Definitions of the reference energy demands, if any, are different for each country and procedures for calculating them depend on the type of building. Therefore, the proposed methodology must be adapted to each situation.

#### *Cost approach*

This is the least frequently used approaches in most cases it is not able to reflect the market properly. In general, this approach is used for properties where the costs play the dominant role. The cost approach takes into account the technical effect and the market effect. One should keep in mind that cost to upgrade does not necessarily equal value. In a nutshell, in this approach, the MAR factor is multiplied by the additional costs between reference buildings in the market and the valuated building.

The project's results and methods have been integrated in the 2010 edition of the European Valuation Standards (EVS). The EVS are published by the European Group of Valuers' Association (TeGoVA). The latest version of the EVS is published in May 2016 <sup>253</sup>.

### **8.3.3.3 How performance improvements were measured**

The key indicators identified were:

- Market value [local currency]

Supporting indicators identified were:

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<sup>253</sup> TeGoVa (2016) *European Valuation Standards* [online], available at: <http://www.tegova.org/en/p4912ae3909e49> [20/5/2016]

- Weighted Adjustment Factor (WAF) [local currency or percentage]

*Direct indicator: market value*

The three proposed modified valuation approaches were tested in different study cases:

1. Ten pilot project valuations applying the income approach, which can be seen as the standard approach prevailing for markets with complex and heterogeneous properties (office, retail, bigger residential buildings etc.): For the given building segments, these entire markets can be interpreted as opaque markets with comparably little (reference) data available.
2. One pilot project on the Romanian market tested the sales comparison approach: The sales comparison approach suitable for homogenous property markets where a lot of data for similar comparables is available. It was therefore tested for multi-family residential buildings (panel buildings) on the real estate market of the city of Iasi.
3. Finally, the modified cost approach was tested for 4 pilot projects. The cost approach is only applied for simple properties; therefore it was tested with the pilot valuation of three single family houses and of one condominium.

The main result of the testing is that all proposed modified valuation approaches work well and generate comprehensive results. There are, however, in practically all cases, significant data problems relating to the lack of availability of EPC and LCC for properties. Although required by regulation, EPCs are not always available in some cases, while LCCA is practically not available at all.

The value impact of the modified approach is for most of the cases very low; practically negligible in all cases except for two around 5% (one calculated with the modified income approach, the other one by the modified sales comparison approach). The main reason is that there still is no proven evidence for higher willingness to pay for energy-efficient properties in the property markets, compared to standard properties. Secondly, the sometimes incomplete data basis forces the valuers to apply very simple benchmarks for cost categories such as operational cost which do not differentiate properly according to the specific building characteristics.

In general, the German property market was observed as having started to recognise the importance of property's energy efficiency and sustainability. The awareness of property owners, tenants, occupiers, etc. of energy efficiency and broader sustainability aspects is rising, but in most cases are still not recognised within decision-making processes.

For one pilot project, the LCC was calculated. In this case, the value impact is around 5%. The reason is the reliable data basis of operational costs and the fact that the subject property is a very sustainable building with superior energy efficiency.

*Supporting indicator – Weighted Adjustment Factor (WAF)*

In the project, the Weighted Adjustment Factor (WAF) expresses the degree to which the market rent for the subject property has to be adjusted (compared to standard values). Figure 8.6 illustrates how the WAF is calculated. It can be quantified using a scoring model, developed by IMMOVALUE: the WAPEC-tool (*WAPEC: Weighted Adjustment for Valuation Parameter Effecting Characteristics*). The WAF is the result of multiplying three parameters:

- the Market adjustment rate (MAR), which states the valuer's estimation of the property market maturity regarding the degree of energy efficiency and other aspects that already affect the property market



- the Average Adjustment Parameter (AAP), is derived from market evidence (if existing) or the valuer's expectations due to replicable argumentation or estimation; and
- the Valuation Estimation Adjustment (VEA), which expresses the valuers' estimated adjustment due to the probability of occurrence, uncertainty, etc. regarding the AAP.

The WAF indicator and related WAPEC tool can be applied in two of the three valuation methodologies focused on by IMMOVALUE: the income approach and the cost approach. Figure 8.7 illustrates the use of the WAPEC tool to calculate the WAF.

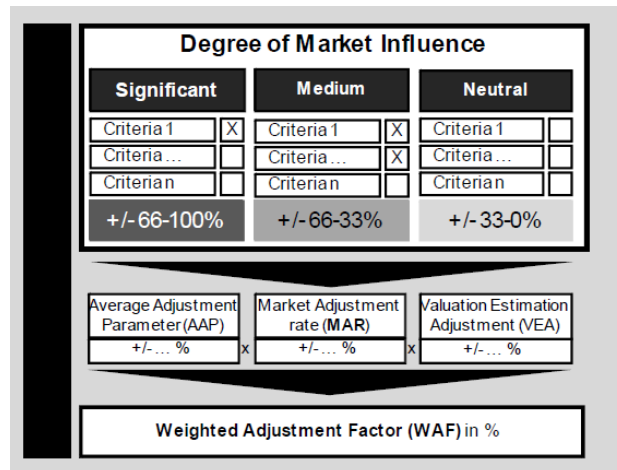


Figure 8.6. Overview of how the Weighted Adjustment Factor (WAF) is calculated

Source: IMMO-VALUE (2010)

Key Valuation Parameter	Market maturity	Significant adjustment	Medium adjustment	Low adjustment	neutral	
Market rent	Opaque (Emerging) Market -> Premium for energetic building (primarily in emerging market)	- high price elasticity - high awareness of tenants for sustainability and energy efficiency - omnipresence of green building issues in the media - high market sensitivity for operating expenses and energy costs (especially in gross rent-orientated property) - good general economic conditions - ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	-> Discount for non-energetic building (mainly in further developed markets)	- building does not achieve energy performance standards/codes - market postulate green building standards/codes - high obsolescence and potential loss of occupier demand - ...	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 20%;"></div> <div style="width: 20%; text-align: center;">+/- 75-100 %</div> <div style="width: 20%; text-align: center;">+/- 50-75 %</div> <div style="width: 20%; text-align: center;">+/- 25-50 %</div> <div style="width: 20%; text-align: center;">+/- 0-25 %</div> </div>				
Market adjustment rate (MAR)		x				
Average adjustment parameter (AAP)*		x				
Valuers estimation adjustment (VEA)*		+				
=> Weighted Adjustment Factor (WAF)		+				
		<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">Key Valuation Parameter (KVP)</div> <div style="border: 1px solid black; padding: 2px;">[€ / m<sup>2</sup> p.m.]</div> <div style="margin: 0 10px;">x</div> <div style="border: 1px solid black; padding: 2px;">Valuation Parameter Adjustment [VPA]</div> <div style="margin: 0 10px;">=</div> <div style="border: 1px solid black; padding: 2px;">[€ / m<sup>2</sup> p.m.]</div> </div>				

Figure 8.7 Example of the WAPEC-tool calculation of the Weighted Adjustment Factor (WAF)

Source: IMMO-VALUE (2010)

The WAF is either calculated in currency or percentage. The largest deviation found is of 3,7% for the Vienna offices building case when considering the full life cycle cost assessment. In currency, the largest variation is of -7.500 EUR for the single family house in Attersee, Austria.

#### **7.4.1.5 Implementation experience of practitioners involved with delivery of the improvements**

The project observed that in valuation practice, it is the lack of data that sets limits for broad application of the modified valuation approaches. In most cases, data on energy efficiency, LCCA and other sustainability aspects are very vague. Although required by regulation, EPC are still missing in many valuation processes while LCC is practically not available at all.

For a broad application, valuers need reliable data bases on reference buildings including not only data on building site, rent level and building equipment but also on energy efficiency and different operational cost categories. In addition, valuers require training making them capable to interpret energy benchmarks, results of LCC and other technical characteristics of the building in a correct way.

These methodologies could be employed to quantify other sustainability issues. If only energy efficiency is accounted for, the AAP can be maximum as high as the annual Energy Cost Saving Potential (ECSP) in percentage. The ECSP is derived by applying the ratio of the gap between the expected cost for energy consumption of a reference building and the property being valued, to the annual rental income. In the case studies analyzed within this project, no other sustainability parameters than energy efficiency and LCC were taken into account.

The value impact of the modified approach was in most of the cases very low. The main reasons for that is that the 'distance' between the subject property and standard buildings on the market with regard to energy efficiency is too low. In general, only for very energy efficient properties with sufficient and reliable reference data on energy and/or operational cost differences, the modified approaches would come up with a premium of 5-10%.

All the case studies highlighted serious data problems relating to the lack of availability of, at a basic level, EPCs and, to support more sophisticated and accurate valuations, LCC projections for the subject property and reference properties.

Today, the current use of the adapted methodologies in the market is unclear. However, EPCs and sustainability aspects are currently specifically addressed in the TEGoVA European Valuation Standards <sup>254</sup>. The research of ImmoValue may have contributed to this.

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<sup>254</sup> TEGoVA (2016) *European Valuation Standards*, 8<sup>th</sup> Edition,

## **8.4 Findings from the operational experience of selected assessment and reporting schemes**

### **8.4.1 Assessment and reporting schemes**

In this section, a summary of the main themes and findings which have emerged from a detailed cross-check of relevant criteria from five certification schemes – BREEAM UK, HQE, DGNB, LEED and VERDE (based on SB Tool) - together with associated interviews are presented.

Reference is also made to the criteria of a number of residential-only schemes – Home Performance Index (Ireland), Home Quality Mark (UK), Klimaaktiv (Austria) and Miljo Byggnad (Sweden) – as well as the GRESB reporting tool.

The main observations are grouped into common themes that emerged from the research.

#### **8.4.1.1 Industry use of Life Cycle Costing**

Feedback suggests that LCC is still not a commonly calculated performance metric and that there are limited drivers to comply with LCC related criteria. Whilst ISO 15686-5 is seen as the reference standard, the scope is considered to be challenging.

In the case of HQE, and based on feedback from their Technical Working Groups and certified building owners, there is the intention to introduce LCC as a new criteria but with a scope limited to building components that clients tend to focus on in order to optimise costs *e.g. HVAC and facades*.

The availability of tools to support LCC calculations was highlighted as an effective way of encouraging greater take-up. A simple spreadsheet based tool and now an on-line tool have been used by DGNB to support applicants. This has reduced the effort required to comply at a 'simplified' level.

#### **8.4.1.2 Life Cycle Costing scope and parameters**

Where costing is specified at building level, a service life of 50 or 60 years is defined. In one case (DGNB), a detailed specification is provided for all components for which lifespans and replacement during this period shall be modelled.

Where costing is specified at building component level, they tend to be divided into categories – for example: *a) Envelope, e.g. cladding, windows, and/or roofing, b) Services, e.g. heat source, cooling source, and/or controls, c) Finishes, e.g. walls, floors and/or ceilings, d) External spaces, e.g. alternative hard landscaping, boundary protection.*

For residential properties, the Spanish VERDE and Irish HPI schemes require only that operational costs for the building owner or occupant are calculated. This is because they are the easiest to communicate at the point of sale. The UK HQM scheme has a broader scope, specifying as part of a 'home owners LCC report' both maintenance costs (major, minor, unscheduled, grounds) and operational costs over 60 years.

The DGNB scheme lays down very prescriptive parameters for carrying out a whole building LCC. This is because, following a preliminary study to develop the criterion, they identified that the LCC goals and parameters on building projects vary. They therefore decided that comparability should be the main objective, and that the methodology laid down should not judge the economic parameters that may be used by different building clients.

To do this DGNB fixes many of the key LCC parameters, regardless of client or geographical location – *e.g. base year, discount rate, building component costs, energy and water costs.*

#### **8.4.1.3 Cost data and assumptions**

Costs should be referenced to a specific year to ensure consistency. In the case of DGNB a reference year is specified for prices (2010) and a discount rate of 5.5% is fixed. An inventory of costs is provided together with a tool which is to be used to calculate the indicator. A maximum of 20% of costs may be based on simplified (generic) data.

#### **8.4.1.4 Property value**

Of the schemes reviewed property value is only currently addressed by a criterion in DGNB. This criterion considers a number of specific factors relating to the location and value compared to other properties in the market.

A number of reporting tools such as GRESB include due diligence checklists that identify present and future risks associated with property assets. These may in turn affect appraisals of value.

### **8.4.2 Progress made by scheme harmonisation initiatives**

#### **8.4.2.1 Common Metrics pilot phase 1, Sustainable Building Alliance**

The Sustainable Building Alliance's initial set of indicators (the 'Common Metrics') does not include a specific criterion on LCC and value

#### **8.4.2.2 Common European Sustainable Building Assessment (New public buildings v1.1), CESBA**

The CESBA assessment scheme does not include a specific criterion on LCC and value in its v1.1 indicator catalogue.

## 8.5 Identification and screening of potential performance indicators

### 8.5.1 Long list of macro-objective 6 direct and proxy indicators

Indicator	Unit of measurement and functional unit	Scope			Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage	Building aspects			
<b>6.1 Life Cycle Costs</b>							
<b>Annual costs</b>	Local currency per year normalised per m <sup>2</sup>	B6/7: Use stage - Operation	Concept design	Operational energy and water use	ISO 15686-5	Normally to be calculated over 50 or 60 years	AR
		B1 – B7: Use stage - Operation - Maintenance	Concept and detailed design	Component level: Envelope, services, finishes, external spaces	ISO 15686-5		FS AR
		A1-5: Construction stage B1-B7: Use stage - Operation - Maintenance	Concept and detailed design	Entire asset at design or as-built stage	ISO 15686-5		FS AR
<b>Net present value</b>	Local currency (for instance €, NOK, Kr, £) or normalized per m <sup>2</sup>	A1-5: Production and construction stages B1 – B7: Use stage	Strategic definition Concept design Detailed design	Entire asset at design or as-built stage	ISO 15686-5	Normally to be calculated over 50 or 60 years	FS AR

6.2 Creating value and managing risk							
<b>Market Value (Gross Development Value)</b>	Local currency (e.g. €, SEK)	B1 – B7: Use stage	Concept and detailed design Refurbishment	Building asset	According to chosen valuation method	-	FS CC
<b>Value uplift</b>	Local currency (e.g. €) per m <sup>2</sup> GFA, GIA or UFA	B1 – B7: Use stage			-	FS CC	
<b>Market churn</b>	Void rate or occupancy rate %	B1 – B7: Use stage			Based on market estimates and/or comparables	-	CC
<b>Value and risk factors</b>	Scoring of weighted criteria	B1 – B7: Use stage		Building, elements and components.	TEGoVA valuation class criteria	-	FS CC
	Reliability rating for risk/value factors	B1 – B7: Use stage			-	-	

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

## 8.5.2 Long list of macro-objective 6 supporting indicators

Indicator	Unit of measurement and functional unit	Scope		Building aspects	Calculation methodology and data sources	Reference conditions and rules	Source
		Life cycle stage	Project stage				
<b>6.1 Life Cycle Costs</b>							
<b>Building service life</b>	Years	B1-7: Use stage	Concept design Developed and technical design Construction Refurbishment	Building asset	ISO 15686 series <i>With reference to cost databases</i>	-	AR
<b>Building element and component life spans</b>	Years	A5: Construction stage B2-4: Use stage - Maintenance - Repair - Replacement		Building elements and components (subject to scope definition)		-	AR
<b>Maintenance plan</b>	Plan for 50 year service life	A5: Construction stage B1-B7: Use stage - Operation - Maintenance		-		AR	
<b>6.2 Creating value and managing risk</b>							
<b>Weighted Adjustment Factor (WAF)</b>	%, €	B1 – B7: Use stage	Concept design Developed and technical design	Building asset value in the property market	IMMOVALUE/TEGoVA	-	FS

Key to sources: FS (Field study findings) CC (Cross Check evidence) AR (Assessment and Reporting scheme criteria)

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