

Interim report

Analysis of field studies to support the identification of options for resource efficient building performance indicators: **FINAL REPORT**

Authors: Van de Vyver Ighor (VITO), Oriane Dugrosprez (ALTO Ingénierie); Contributors: Carolin Spirinckx (VITO), Marianne Stranger (VITO), Wim Debacker (VITO), Jef Bergmans (VITO), Omar Amara (VITO), Yixiao Ma (VITO), Virginia Gomez Onate (VITO), Manon Kayser (ALTO Ingénierie); Review: Karen Allacker (KUL)

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This study is performed by

VITO



in close collaboration with

and

KU LEUVEN



VITO NV

Boeretang 200 - 2400 MOL - BELGIE
Tel. + 32 14 33 55 11 - Fax + 32 14 33 55 99
vito@vito.be - www.vito.be

BTW BE-0244.195.916 RPR (Turnhout)
Bank 375-1117354-90 ING
BE34 3751 1173 5490 - BBRUBEBB

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- Yixiao Ma
- Jef Bergmans
- Omar Amara
- Virginia Gomez Onate

ALTO Ingénierie:

- Oriane Dugrosprez
- Manon Kayser
- Kevin Marchand

KU Leuven (ASRO):

- Karen Allacker

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GLOSSARY

| | |
|------|--|
| AAC | Autoclaved aerated concrete |
| ACH | Air change per hour |
| BAF | Biotope Area Factor |
| BBC | Low energy building (in French: <i>Bâtiment basse consommation</i>) |
| BIM | Building information model |
| BMS | Building management system |
| BU | Business unit |
| C&D | Construction and demolition |
| CAD | Computer aided design |
| CC | Cross-Check |
| DSY | Design summer year |
| EoL | End of life |
| EPBD | Energy performance of buildings directive |
| EPC | Energy performance certificate |
| EPD | Environmental product declaration |
| FS | Field Study |
| GFA | Gross Floor Area |
| GHG | Green house gas |
| GSF | Green Space Factor |
| GWP | Global warming potential |
| IAQ | Indoor air quality |
| IDA | Indoor air |
| LCA | Life cycle analysis |
| LCC | Life cycle cost |
| LCI | Life cycle inventory |
| MDF | Medium density fibreboard |
| MO | Macro-objective |
| NFA | Net Floor Area |
| ODA | Outdoor air |
| OEF | Organisational Environmental Footprint |
| OSB | Oriented strand board |
| PEF | Product environmental footprint |
| PM | Particulate matter |
| PMV | Predicted mean vote |
| PPD | Predicted percentage dissatisfied |
| REB | Resource Efficient Buildings |
| SG | Stakeholder Group |
| SVOC | Semivolatile organic compounds |
| TRY | Test reference year |
| TVOC | Total volatile organic compounds |
| UFP | Ultrafine particle |
| VCM | Vinyl Chloride Monomer |
| VOC | Volatile organic compound |
| ZLC | Zero low carbon |

EXECUTIVE SUMMARY

1.1. INTRODUCTION

The European Commission adopted the Communication on Resource Efficiency Opportunities in the Green Building Sector in 2014 (COM 445 (2014)¹), which describes the aim to enlarge the scope of “sustainable” or “green” buildings. The main objective of that initiative is to promote a more efficient use of resources consumed by new and renovated commercial, residential and public buildings and to reduce their overall environmental impacts throughout the full life cycle. To support this development, reliable, comparable and affordable data, methods and tools are needed, however these are still lacking to a certain extent today. This situation results in an absence of guidance on how to incorporate environmental considerations in purchasing decisions.

The main objective of the Communication on Resource Efficiency Opportunities in the Green Building Sector (COM (2014) 445) is to influence decision-making along the life cycle of buildings by providing relevant and comparable information regarding their environmental performance. This will be done by developing an assessment framework with core indicators. The assessment framework can be used on its own or as a module next to other indicators in existing or future certification schemes (commercial or public). This work on the development of the assessment framework with core indicators (the “Resource Efficient Buildings” study or REB-study) is led by JRC. It has started in January 2015 and will run for 30 months.

The study carried out by Flemish research institute VITO, together with environmental engineering firm ALTO from France and university KU Leuven from Belgium, contributed to this identification of options for building resource efficiency performance indicators. Subject of this study was the analysis of field studies – real-life building projects. The overall goal of the analysis of the field studies was to investigate how key aspects of resource efficient buildings are implemented in practice at building project level and which indicators are used for this purpose.

In December 2015, the JRC finalised Working Paper 1 on macro-objectives. With this paper, the JRC identified six main themes for resource efficient buildings or “macro-objectives”[JRC, 2015]. The macro-objectives paper provided the starting point for this study.

1.2. TERMINOLOGY

1.2.1. MACRO-OBJECTIVES

The six macro-objectives focus on the building level and are grouped under two headings - ‘life cycle environmental performance’ and ‘quality, performance and value’. An overview of the macro-objectives is provided in Table 2.

¹ Decision No 445/2014/EU of the European Parliament and of the Council of 16 April 2014 establishing a Union action for the European Capitals of Culture for the years 2020 to 2033 and repealing Decision No 1622/2006/EC

Table 1: Overview of macro objectives and aspects covered [IPTs, 2015]

| Life cycle environmental performance | |
|---|---|
| Macro-objective | Aspects covered |
| B1: Reduction of greenhouse gas (GHG) emissions from building life cycle energy use | <ul style="list-style-type: none"> - Operational carbon emissions - Embodied carbon emissions |
| B2: Resource efficient material life cycles | <ul style="list-style-type: none"> - Lean design - Circular flows - Material utility - Environmental impact |
| B3: Efficient use of water resources | <ul style="list-style-type: none"> - Water efficiency - Water scarcity |
| Quality, performance and value | |
| Macro-objective | Aspects covered |
| B4: Healthy and comfortable spaces | <ul style="list-style-type: none"> - Exposure to hazardous substances – ventilation intake air - Exposure to hazardous substances – materials emissions - Exposure to hazardous substances – (de)construction of building components - Moisture and mould |
| B5: Resilience to climate change | <ul style="list-style-type: none"> - Green infrastructures - Thermal tolerance |
| B6: Optimised life cycle cost and value | <ul style="list-style-type: none"> - LCC - Value |

1.2.2. PERFORMANCE INDICATORS

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.

It is important to stress that the aim of the analysis is to identify indicators as much as possible on the level of the macro-objective or indicated sub-aspects on the one hand and the building level on the other hand. For instance, in the case of operational carbon emissions, this translates to focusing on indicators such as primary energy consumption or operational carbon emissions and to a lesser extent on individual U-values of building components (e.g. wall, floor, roof or windows).

It is considered important that any indicator identified supports the realisation of the Commission's anticipated benefits and advantages, as indicated in COM(2014)445. 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: 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 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 of the JRC. 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.

1.2.3. BUILDING TYPES AND PROJECTS

The scope of the study to focus on residential and office buildings [IPTs, 2015]. 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.

1.2.4. 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) ².

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.

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

Box 2: 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
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

1.2.5. BUILDING LIFE CYCLE STAGES

Furthermore, 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 4 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.

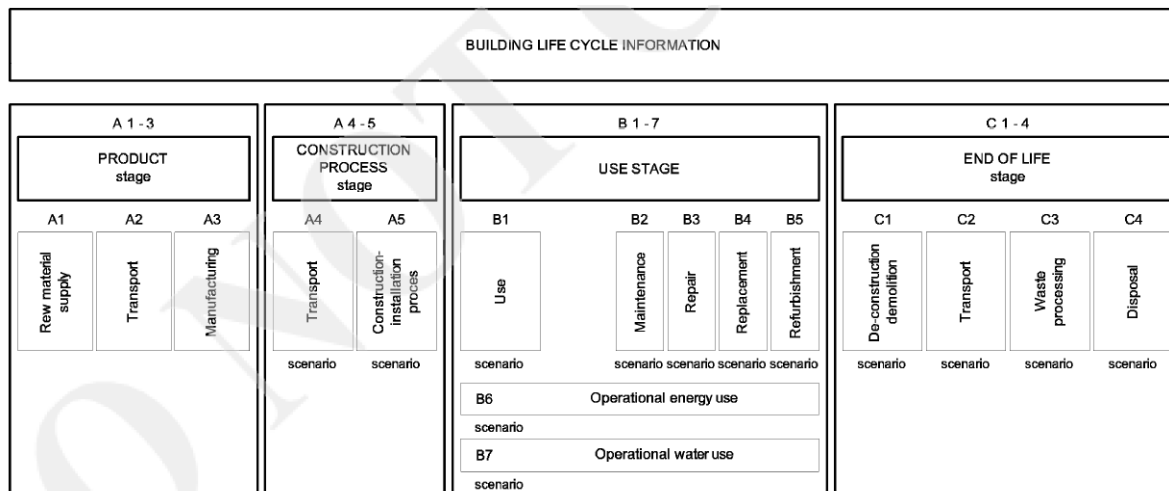


Figure 1: Scope of building life cycle stages to be considered. Source: CEN (2011) Methodology

1.3. METHODOLOGY

1.3.1. FRAMEWORK OF THE ANALYSIS

The aim of this study was to investigate how the six macro-objectives were translated into meaningful and practical performance improvements in a real-life building project. Therefore, various field studies were selected for an in-depth analysis.

In the context of this study, field studies are understood to be monitoring and evaluation studies encompassing a range of office and/or office buildings, either new-build or renovation, where major environmental improvements have been made. The 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).

Two key priorities were taken into account during the selection process:

- Coverage of each (identified aspect of the) macro-objective;
- Experience of real-life practice, in particular assessment schemes or building permit requirements.

Furthermore, particular attention has been made to include, as far as possible, relevant influences such as different professional and regulatory contexts; building typologies, forms and ages; as well as possible geographical and cultural variations. A number of additional study objects (in this report further referred to as “cross-checks”) were selected to further ensure that any gaps in the technical scope and coverage of the field studies were addressed.

The analysis was conducted in two steps. In the first step, potential study objects were screened with the outcome a final selection of field studies and cross-checks. In the second step, data was collected for each field study. The objective of this data collection was to identify the targets, benchmarks or indicators and the technical data, methodologies and evaluation tools in these field studies that were used to monitor and achieve these performance improvements. It also considered project processes, drivers and responsibilities within the design team. Therefore, the three research questions are as follows:

1. How has the specific macro-objective been translated into action at project level?
2. Which indicators were used to measure the performance improvement(s) and what is the associated methodology for quantification?
3. Which lessons can be learnt from the experience of measuring and verifying the performance improvement(s)?

1.3.2. SELECTED FIELD STUDIES

In total, nineteen field studies were selected were put forward for further analysis by VITO and ALTO.

The selection of field study evidence has been compiled based on the following main sources:

- Actual building and masterplan projects of ALTO, certified with BREEAM, DGNB, HQE and LEED. Examples: ZENORA offices;
- Evaluation studies of VITO focusing on relevant aspects of the macro-objectives identified. Examples: Ghandi/Hoogbouwplein (material utility), Renovair (Indoor Air Quality);
- Studies based on literature and information from stakeholders gathered to date by the JRC. Examples: Skanska plc.

A brief description of each field study is provided in the following sections. The detailed analyses are compiled in the “catalogue of field studies”, which is included as Annex I to the final report.

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” and cluster 3 “ALTO – residential masterplan”. 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. 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). The analysis for each project covers the methods, tools, databases and indicators associated with specific versions of the certification scheme, which are mentioned for each project.

Boulevard Mac Donald is an urban redevelopment masterplan in the north of Paris, France. It centres around the rehabilitation of the old Mac Donald 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 the 15 building units.

The buildings had to achieve the following certifications: “*Habitat & Environment (H&E)*”³ and “*Bâtiment Basse Consommation (BBC)*”⁴.

The cluster “ALTO offices – new build” 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 in France. It is certified according to HQE, BREEAM and HQE performance. The versions used are: HQE construction v2008, BREEAM v 2009 and HQE performance.

The cluster “ALTO offices – renovation” 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.

The **Venning District** in Kortrijk, Belgium is part of the project “ECO-Life”. The project was commissioned by the social housing company “Goedkope Woning” in Kortrijk. ECO-life is a European demonstration project funded under the framework of the CONCERTO initiative. The buildings analysed are social housing, consisting of 82 residences in four multi family houses and 114 single family houses, which were monitored by the university of Ghent. Objective of the research project was 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 CO₂ level).

The **Mahatma Ghandi district** is a social housing neighbourhood in Mechelen (Belgium). Redevelopment of the district was organized by the social housing corporation “Woonpunt Mechelen”. The redevelopment provided the opportunity to develop and apply “Design for Change”. Design for Change is a framework developed by the research institute VITO and the universities KU Leuven and VUB⁵. It includes a qualitative and a quantitative part. The qualitative

³ Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

⁴ BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

⁵ 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

part contains of a set of 23 practical design guidelines on district, building and element level. The quantitative part consists of Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) analysis. The LCA is based on the Belgian assessment method MMG⁶, in line with EN15978⁷ and the ILCD Handbook⁸. The LCC is based on the Belgian Science Policy project SuFiQuaD⁹. The Design for Change framework was applied in a follow-up building project by KPW architects, an apartment block on **Hoogbouwplein** in Zelzate, Belgium.

ENSLIC (ENergy Saving through promotion of Life Cycle assessment in buildings) was an Intelligent Energy Europe (IEE) project¹⁰, which started in 01/10/2007 and ended in 31/03/2010. Nine partners from as many countries (Austria, Netherlands, France, Spain, Germany, Hungary, Norway, Sweden, Bulgaria) were involved. ENSLIC explored how to simplify LCA with the purpose of increasing the use of LCA in the building practice. Proposed simplifications include limiting the number of life cycle stages to production (A1-A3) and operation (B1-B7); and limiting the number of impact categories (for instance, only global warming potential). ENSLIC focussed on primary energy use and climate change potential indicators. The cases covered in ENSLIC are assessments of existing designs or buildings.

The **Skanska Group** is a private project development and construction group, active in North America and Europe (in particular Northern Europe, Eastern Europe and the UK). With regards to using carbon footprinting in the building practice, the Skanska Group has build-up extensive experience in several EU Member States. The field study analysis draws upon Skanska's public database of pilot projects¹¹ and interviews with representatives from individual Business Units (BUs) in Sweden, Norway, UK, Poland, Czech Republic and Hungary.

The **Building Performance Indicators** are an initiative of the **Green Building Council Finland (GBCF)**, 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 open-source and publicly available on the website of GBCF. 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). Currently, the GBCF's database of buildings contains 20 to 25 project entries (with the majority comprising of office buildings).

Report (in Dutch), study commissioned by the Public Waste Agency of Flanders (OVAM), available through <http://www.ovam.be/veranderingsgerichtbouwen>

⁶ 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

⁷ CEN (2011), EN 15978 Sustainability assessment of construction works – assessment of environmental performance of buildings – calculation method

⁸ 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.

⁹ 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.

¹⁰ <https://ec.europa.eu/energy/intelligent/projects/en/projects/enslic-building>

¹¹ Skanska (2012) Aspects of sustainability – case studies [online], available at <http://www.skanska-sustainability-case-studies.com/> [20/5/2016]

IRCOW was 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 on-site solutions. Thirteen partners from seven countries were involved (Belgium, Sweden, Poland, Spain, Italy, Germany and Finland), among which Tecnia (coordinator) and VITO. IRCOW developed and validated upgraded technological solutions to achieve an efficient material recovery from (C&D) waste by considering a life cycle perspective. The analysis focused on two of the five case studies: selective demolition of an industrial/service building in Spain and the demolition of office buildings related with construction of non-residential buildings in Spain and Belgium.

Officair¹² 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.

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 schools¹³. The study was conducted by VITO, in collaboration with the University of Ghent, the Belgian Building Research Institute (BBRI) and the National Institute for Health and Welfare in Finland (THL). 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. The study included twenty-five low energy residences, which were built in Flanders between 2008 and 2011.

Renovair is a pilot study in the Flemish region (Belgium). 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. 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 Renovair study is a follow-up of the Clean Air Low Energy study. The research questions, methodology and results are very similar.

INSULAtE is a European project, co-financed by the EU Life+ programme¹⁴. The research objectives, methodologies applied and indicators assessed in INSULAtE are similar to the ones covered in Renovair, but INSULAtE focusses on the Scandinavian (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 (follow-up) assessment (after retrofits in the case buildings). INSULAtE

¹² Officair (2013) *Officair* [online] <http://www.officair-project.eu/> [20/5/2016]

¹³ Clean Air, Low Energy (2012), <https://esites.vito.be/sites/cleanairlowenergy/EN/home/Pages/home.aspx>

¹⁴ http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3725

addresses macro-objective B4 “Healthy and comfortable spaces” and in particular the exposure of hazardous substances as a result of ventilation intake air and material emissions. Moisture and mould is considered as well, but to a lesser extent.

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.

The **Design for Future Climate (D4FC)** 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 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: The Co-operative headquarters by Buro Happold; 100 City Road in London by ARUP and the Admiral Insurance HQ in Cardiff by Glen Howell. In these cases, climate change risk assessment was carried out using UKCP09 climate projections (e.g. for 2030s and 2050s). Dynamic thermal modelling was used to predict the energy use and internal comfort for these future scenarios.

The **Knowledge for Climate (K4C)** Research Program conducts research 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. A study selected from the K4C programme quantifies the effectiveness of climate change adaptation measures applied at the level of building components for three common residential building typologies in The Netherlands (detached house, terraced house, apartment). The 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.

In 2006 the consultancy firm **Davis Langdon (UK)** developed a **common European methodology** for Life Cycle Costing (LCC) in construction taking into account the work done under international standard ISO 15686. The study included the analysis and evaluation of the different national approaches for LCC, as well as elaborating an approach for the estimation of Life Cycle Costs and related indicators for buildings and constructed assets which could be of added value at EU level. The common methodology for Life Cycle Costing was applied in a number of cases across Europe with different objectives.

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 LCC analysis 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 were included as well.

ImmoValue (*property valuation, linking energy efficiency of buildings and property valuation practice*) was an Intelligent Energy Europe (IEE) co-funded project¹⁵, with international consortium of six partners from four countries (Romania, Austria, Germany and Sweden). Coordinator was KPMG Financial Advisory Services GmbH (Austria). Relevant associations for property valuation, i.e. the Royal Institute of Chartered Surveyors (RICS) and The European Group of Valuers Association (TEGoVA) were involved as well. The project started in 01/09/2008 and ended in 30/04/2010. The IMMOVALUE project is a notable example of an EU project that has sought to develop modified property valuation methodologies. It focussed on three common approaches to calculate market value (income related, sales comparison and cost approaches). The aim of these modified approaches was to reflect energy efficiency and LCC analysis in a more transparent and quantitative way.

1.3.3. SELECTED CROSS-CHECKS

In addition to the selected field studies, twelve cross-check studies were identified to further complement the findings of the analysis. A summary description for each cross-check is included in Annex II of the main report.

ASIEPI (Assessment and improvement of the EPBD Impact (for new buildings and building renovation)) was an Intelligent Energy Europe project from October 2007 to March 2010. It focused on issues such as compliance with European legislation on the energy performance of buildings, the inter-comparison of building energy performance across Europe, plus specific topics such as thermal bridges, summer comfort, ventilation and the use of innovation in buildings have been tackled.

The **Database of embodied Quantity outputs (deQo)** is an online database containing the material efficiency and embodied carbon of building structures. The database is developed at the Structural Design Lab within the Building Technology program at MIT as part of the thesis-research of Catherine De Wolf, PhD researcher at MIT university.

In the **Netherlands**, building permitting requires the assessment of the environmental performance of new-build residential and office buildings according to a national assessment method (**Assessment Method Environmental Performance Constructions and Civil Engineering (GWW) Works**)¹⁶.

Concerning demolition works, **Belgium** has specific **federal and regional (Flanders) regulation related to material inventories and mandatory sorting of C&DW**. An asbestos inventory prior to demolition/refurbishment is compulsory for every type of building, if the demolition works are performed by a professional company (*KB 16/03/2006*)¹⁷. A material inventory prior to demolition is compulsory for buildings of more than 1.000 m³ with a (partial) non-residential function

¹⁵ European Commission (2016) *IMMOVALUE* [online], available at:

<https://ec.europa.eu/energy/intelligent/projects/en/projects/immovalue> [20/5/2016]

¹⁶ <http://www.bouwbesluitonline.nl/inhoud/docs/wet/bb2012/hfd5/afd5-2/art5-9>

¹⁷ KB 16/03/2006 regarding the protection of employees against the risks of exposure to asbestos

(VLAREMA 1/06/2012, art. 4.3.3)¹⁸. VLAREMA (1/06/2012)¹⁹ obliges separation at source of several company waste streams.

Tracimat is a construction and demolition waste (CDW) management organization in Flanders (Belgium), founded by the Flemish Construction Confederation (VCB). 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. Tracimat is one of the activities of the on-going European H2020 project Hiser²⁰.

In 2010, the Finnish Government launched a national program to combat moisture and mould issues in the Finnish building stock: the **Finnish moisture and mould program**. Main outcome of the program is awareness raising and sensitizing of citizens regarding moisture and mould issues in the indoor built environment in Finland.

A study conducted by the Finnish research institute VTT²¹ measured 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. The study is linked to the **Finnish Indoor Climate Classification** in Finland²².

HITEA – Health Effects of Indoor Pollutants: Integrating microbial, toxicological, and epidemiological approaches – is a collaborative EU study, co-funded under the Seventh Framework Program (FP7)²³. The study focused on dampness and moisture problems and associated exposures to biological agents in schools and residences. It included the development of a common assessment methodology for dampness and mould, with standard protocols for the data collection and a centralized database.

The building regulations of the city of Berlin require that a certain proportion of new project developments have to be left as a green space. The proportion of green space to the entire development area is referred to as the **Biotope Area Factor (BAF)**. The BAF inspired other regional authorities in Europe to develop similar indicators. For instance, in Malmö and Southampton the **Green Space Factor (GSF)** and the **Green Point System** were developed under the framework of the European Interreg project GRaBS²⁴. In the city of Basel, building regulation requires green roofs on all new and renovated flat roofs.

SuFiQuaD is a LCA/LCC study for residential property in Belgium. The aim of the SuFiQuaD project (Sustainability, Financial and Quality evaluation of Dwelling types) was to develop a methodology and tool to evaluate both the initial and life cycle costs (financial and environmental external) and benefits (qualities) of buildings (or building parts), based on data representative for Belgium.

¹⁸ *Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen*

¹⁹ *Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen*

²⁰ <http://www.hiserproject.eu/>

²¹ Järnström, Helena. 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.

²² FiSIAQ, Finnish Society of Indoor Air Quality and Climate: Classification of Indoor Climate 2000. Espoo, 2001

²³ http://cordis.europa.eu/project/rcn/87924_en.html

²⁴ Interreg IVC (2011) Green and Blue Space Adaptation for Urban Areas and Eco Towns (GRaBS), available at: <http://www.interreg4c.eu/projects/project-details/?project=10-green-and-blue-space-adaptation-for-urban-areas-and-eco-towns&> [20/06/2016]

ReValue and **RenoValue** are two collaborative EU studies of valuation techniques. Both are co-funded by the Intelligent Energy Europe (IEE) program. The aim of RenoValue was to strengthen the role of valuation professionals in the market transition towards Nearly Zero Energy Buildings (NZEB). The aim of ReValue was to lead the development of appraisal norms and standards that recognise energy efficiency value in social and private residential real estate.

1.4. SUMMARY OF FINDINGS PER MACRO-OBJECTIVE

For each field study the following aspects were investigated to answer the research questions as formulated earlier:

- The process by which the **improvement options** were identified and chosen, what the options were and how they were then integrated into the building specifications. In particular the **targets, benchmarks or indicators** that were used as evaluation criteria for these improvement options;
- The **methodologies, tools, data sources** and standards used by the building design team and main construction contractor to successfully implement and monitor the performance improvement options during the different stages of the building (such as design stage, construction, use stage);
- The roles and responsibilities of the **different actors within the project process** in implementing the improvement options, and success factors in ensuring their engagement in implementation;

The findings of the field studies and cross-checks analysis are summarized in the final report per macro-objective structured according to the following topics:

1. Improvement options
2. Tools, methodologies and standards
3. Data requirements
4. Processes and actors
5. Inventory of lessons learned
6. Indicator options

The main outcome is a list of identified indicators per macro-objective and a summary of key factors to consider when formulating indicator proposals.

1.4.1. GREENHOUSE GAS EMISSIONS FROM BUILDING LIFE CYCLE ENERGY USE (MACRO-OBJECTIVE B1)

Carbon emissions, normalized per gross floor area (m²), is an indicator that covers the full scope of this macro-objective. A distinction has to be made between an operational part and embodied part. The sum of operational carbon emissions and embodied carbon emissions result in the total carbon emissions or carbon footprint of a building. However, comparability among different regions and Member States requires caution, as scope and assumptions can differ in the case of operational (and likely, also embodied) carbon emissions.

→ Key factors to consider – Operational carbon emissions

- The operational part of the carbon emissions is inevitably linked to the regional and national EPBD-regulations. While the EPBD and its recast provides a European framework,

calculation methodologies still differ significantly among the different Member States. It is difficult to define a common indicator, as there is a large variation in performance targets, data requirements, scope and boundary conditions. The advantage is that the building practice is very familiar with it;

- Dynamic simulations have the potential to assess operational energy use more accurately than steady-state simulations, but a gap between predicted and actual energy use is still very likely. Furthermore, it has to be taken into account that dynamic simulations are more complex, require more skills and efforts, and can result in additional costs. Therefore, when dynamic simulations are used, it might be necessary to provide specific guidelines to clearly define the assumptions in order to minimize the gap between predicted and actual energy use;
- Solar heat gains are better captured/calculated in dynamic simulations than steady-state simulations and therefore, dynamic simulations are typically used to address thermal comfort and overheating issues;
- Quality assurance tests such as air-tightness tests or thermographic scans are useful to confirm the quality of the construction works. However, depending on the timing of the tests, it might be difficult to steer improvement if needed;
- It has to be taken into account that quality assurance tests are likely to involve a third party and thus imply additional costs. Furthermore, depending on the test, it can sometimes be difficult to execute valid practical tests due to the measurement error or other issues such as weather conditions;
- There is an important cross-link with thermal comfort and with MO B4a “Healthy and comfortable spaces”, in particular an appropriate ventilation strategy, which is inevitably linked with the air-tightness level of the building envelope.

→ Key factors to consider – Embodied carbon emissions

- There seem to be no commonly accepted benchmark values that can function as absolute performance target values;
- The scope and assumptions used for the embodied carbon calculations differ significantly, in particular concerning the life cycle stages (production, construction, use and end of life) and the building components (structure, facades, technical installations) to consider;
- The availability of consistent, reliable and accurate databases with emission data on national (or regional) level are identified as a barrier. In addition, as there is a lack of common guidelines, databases use different assumptions and hinder comparability of results. This points out the need for a common methodology on European level but with (open-source) databases on regional or local level;
- Material quantities are typically obtained from cost estimations, bill of materials and BIM-models. Quality assurance and data verification are highlighted as a point of attention;
- Current building practice is not very familiar with embodied carbon assessments as it is not widely applied yet. However, there is a potential to embed carbon footprinting in the existing practice of existing actors, more in particular the (main) contractor or structural engineer;
- Initially focusing on the building’s structure could be a way forward, as the structure causes a significant contribution to the building’s carbon emissions²⁵; building materials used are conventional materials and as such, data availability is less of an issue; and it relates directly to the practice of certain building actors i.e. the structural engineer and the

²⁵ De Wolf, C., 2014, *Material quantities in building structures and their environmental impact*, Massachusetts Institute of Technology, p. 10

contractor. This initial scope can be expanded, for instance with additional specifications for certain building components (e.g. façade elements or wooden structures).

1.4.2. RESOURCE EFFICIENT MATERIAL LIFE CYCLES (MACRO-OBJECTIVE B2)

It is not possible to define an indicator on the level of the macro-objective. Indicators for B2 should be defined for its sub-aspects.

→ Key factors to consider – Circular flows

- Recovery ratio by weight can be a useful indicator. The difficulty to reach recovery ratio targets depends on the country context. In fact, the analysis of the field studies identified that conditions for C&D waste management vary significantly among Member States. Market and policy factors have a large impact, for instance in providing financial incentives and to set a proper construction culture/context;
- Another option is to not only focus on material streams but on the reuse of whole buildings, or major elements such as structures and foundations;
- Construction waste is easier to recover/recycle/reuse than demolition waste (e.g. bricks). Construction waste is less mixed than demolition waste because pure fractions can be obtained during construction;
- As already pointed-out, it does not address the type of recovery and the quality of the recovered material. In addition, it only addresses to a certain extent the minimization of waste. As a result, an indicator on mass arising can be explored further as it was not fully covered in the analysed field studies;
- Recovery ratios do not provide information about the type of recovery (reuse, recycling, energy recovery). Furthermore, recovery ratios don't necessarily reflect the quality of the produced material streams. In order to achieve high-grade recycled material, the amount of unwanted constituents in material streams needs to be limited. This can be achieved by a selective demolition process. If no selective demolition was conducted, mixed material fractions might have to be sorted out, either manually, which can be time-consuming, or by using advanced sorting techniques to obtain high-quality material fractions;
- The selective disposal of non-recyclable hazardous waste is crucial for a viable circular economy. Purer waste streams with a low environmental risk clearly have a greater upcycling potential. Non-recyclable hazardous waste could be excluded from the recovery ratios;
- Finally, the amount of recycled material in a new product as an indicator certainly has its merits. However, recycled content does not provide information on the quality of the end-product (durability) or the efficiency/quality of the recycling process (for instance, if the end-product was the result of "upcycling" or "down-cycling"; a recycled product that would be recycled anyway versus a recycled product that would normally be disposed). The impact of a replacement with recyclable materials on sustainability depends on several factors (e.g. primary material that is replaced, type of recycled material, transport distances). To include these factors, LCA studies are necessary.

→ Key factors to consider – Material utility

Future adaptation potential

- Whilst the potential for future adaptability of buildings is highlighted in literature as being an important consideration, there are no mature indicators currently in use;
- From a standardisation perspective, EN 15643-3/EN 16309 provides some limited pointers as to measures to increase adaptability. ISO 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17;
- A composite score can be derived, for instance based on a checklist as included in the DGNB-scheme, which could form the basis for an indicator for office buildings;
- Increasing the future adaptation potential of the building has to be addressed early in the design process. The architect and structural engineer hence play a key role. Guidelines and recommendations that specifically address the design process have a large potential to steer improvement in this aspect.

Disassembly potential

- A greater consideration at design and construction stage of the building's end of life (ease of dismantling/separability of building elements are cited) should be primary considerations for design teams and clients;
- The state of the art is a category scoring for ease of disassembly, scope of disassembly and viability of disassembly (DGNB). This could form the basis for an indicator, with the scope defined in order to focus attention on hotspot building elements;
- A strong relationship is identified with MO B6 "life cycle cost and value", more in particular the design life and/or service life for a building, elements and components are considered in a number of certification schemes.

→ **Key factors to consider – Environmental impact**

- The main methodology applied is Life Cycle Assessment (LCA) according to LCA standards such as ISO 14040-14043, EN 15978, EN 15804 and ISO 21930;
- In practice, LCA is commonly applied on building component level to compare different design or construction options. LCA on building level is less common, although certification schemes are evolving towards this approach in recent versions;
- Simplified LCA-tools such as BREEAM's Green Guide and HQE's Elodie, but also certification (e.g. FSC-labels) and classification systems (e.g. NIBE) are reported to be user-friendly and more easy to use in early design stages. However, assumptions in the tool or methodology (for instance regarding life cycle stages and environmental impact considered, or databases used) are not always transparent or clear (e.g. Green Guide which has a "black-box" approach);
- A key discussion point is whether to use a set of individual (impact) indicators (for instance, the seven impact categories defined by CEN TC350), or to use an aggregated/weighted (set of) indicator(s);
- Using a set of individual indicators makes it difficult to compare two or more building or building element alternatives. Hence, decision-making based on an (independent) set of individual life cycle impact indicators is not practical. This is true for designers, building clients, but also for policy actors. Option 1 is used for 'hot-spot analysis';
- Using an aggregated indicator (a single indicator covering ALL individual impact categories, after a normalization step and weighting) is a practical solution for comparisons and decision-making (based on comparisons), but is further away from the real environmental mechanism. Furthermore, there is no consensus on a 'universally accepted weighting scheme';

- It is recommended to align the development of Core Indicators with the CEN TC350 and/or PEF activities;
- There is a strong relationship with B1 embodied carbon, as Global Warming Potential is one of the impact categories that is assessed in LCA.

1.4.3. WATER USE (MACRO-OBJECTIVE B3)

→ Key factors to consider

- A clear distinction can be made between office and residential projects. A key difference is the fact that performance targets for water consumption are defined on the level of the building (normalized per person) in case of office projects and on the level of the sanitary appliances (as a target flow rate) in case of residential buildings;
- Design assumptions and threshold values of flow rates for sanitary appliances vary per certification scheme. The LEED certification scheme was reported to have the most stringent criteria;
- There is no key standard identified. A number of tools to calculate the water consumption during a building's use have been identified in the certification schemes. The main differences are: the level of transparency of the tool, input parameters required, and water use considered (both on the "demand side" (i.e. non-potable water use such as cleaning or irrigation) as the "supply side" (i.e. rainwater harvesting, grey water reuse). For these reasons, the approach of DGNB seems to be the most complete;
- Regarding water demand strategies, more in particular rainwater harvesting and grey water reuse, it is noted that regional or national regulation can have an important influence.

1.4.4. HEALTHY AND COMFORTABLE SPACES (MACRO-OBJECTIVE B4A)

The analysed field studies indicate a strong relationship between a building's ventilation strategy, the exposure to hazardous substances from building product emissions and exposure to hazardous substances from outdoor air sources. Hence it seems appropriate to use a holistic approach instead of focussing on these aspects separately. Reference is made to EnVIE²⁶ and HealthVent initiatives, which put forward a framework based on the following three principles:

- Limit entrance of pollutants from outdoor;
- Limit pollutants from indoor sources by choosing low emission cleaning products, building materials and furniture;
- Limit exposure by using a ventilation strategy based on health criteria.

→ Key factors to consider –ventilation strategy and ventilation intake air

- Concerning the exposure to hazardous substances resulting from the ventilation intake air, a distinction can be made between improvement options that target specifically hazardous substances as the result of the intake (of outdoor) air and improvement options that focus on the performance of the ventilation system;

²⁶ EnVIE (2009) *Objectives and approach of EnVIE* [online], available at: <http://paginas.fe.up.pt/~envie/> [20/5/2016]

- Regarding the first point, in a number of field studies (especially the office projects), criteria are put forward to limit the intake of outdoor pollutants, either qualitatively by specifying requirements for the location and distance of air intake and exhaust openings or quantitatively by specifying filter class requirements;
- European standard EN 15251 offers several options, such as based on CO₂-level or a design ventilation rate that takes into consideration both the ventilation rate per person (i.e. occupants as the main source of pollution) and per square meter floor area (i.e. pollutions from material emissions);
- Performance targets for ventilation flow rates are defined on room-level, rather than on building level;
- A distinction can be made between residential and non-residential buildings. This results in other performance targets and approaches;
- There is a strong relationship between the ventilation strategy and energy performance, as already indicated previously.

→ **Key factors to consider –material emissions**

- The determination of the concentration levels of hazardous substances can be performed using different analytical methods and techniques, and can be expressed in various units. The ISO-16000 is identified as key standard in this regards. A clear distinction can be made between approaches which imply product emission testing and approaches which focus on in-situ air measurements;
- In the case of product emission testing, the scope of the assessment of hazardous substances is largely focused on VOCs and formaldehyde. This initial scope can be enlarged for certain product groups. In general, building aspects considered include the building materials related to interior floor finishing, wall or ceiling covering. Assets such as furniture and cleaning products, which are closely related to user behaviour, are typically not considered, although the results of emission tests of a typical office setting in the Officair field study indicated that they can have a significant contribution to the IAQ;
- In the case of in-situ air measurements, it is observed that the scope of the assessment of hazardous substances is broader. In addition to formaldehyde and VOCs, the following pollutants are included in the assessment of at least one field study: CO, CO₂, NO₂, O₃, particulate matter (PM_{2.5}, PM_x and PM₁₀) and Radon. Furthermore, the total VOC-level (TVOC) can be calculated as well;
- Timing (winter or summer) and location of the in-situ measurements (i.e. the room or space to conduct the measurements) can have a significant influence on the results. There is also a link between the timing and the scope of the assessment (e.g. pre- or post-occupation, depending on the fact if only interior is considered or user behaviour as well);
- In-situ air measurements have to be seen as quality assurance;
- It is difficult to identify the approach which is best in terms of minimising risk of exposure. The majority of criteria of the certification schemes target indoor finishing, but there is not a clearly defined priority list. This should clearly relate to the goal of the assessment: does the assessment target the building, the interior or the equipment? The field studies indicate a strong relationship between the building/equipment aspects that are considered, the assessment method and the scope of the hazardous substances;
- It is difficult to capture the influence of user behaviour and context factors (for instance the location of the building and possible external pollution related to it).

→ **Key factors to consider – Moisture and mould**

- Measurement of damp and mould is a relatively new area, and it appears that test methods to evaluate levels in-situ are relatively undeveloped for widespread use;
- Qualitative methods to assess moisture and mould issues have been identified, such as a survey targeted at building managers or occupants, and a walkthrough with check-list for a detailed inspection of trained experts;
- Quantitative methods that have been identified concern air and surface sampling by accredited third parties. ISO 21527-1 and ISO 4833 are found to be the key standards for the analysis of fungi and bacteria respectively;
- The field studies indicated a number of national standards that put forward performance target values for concentrations of bacteria and fungi, such as the French standard XP X 43-401 or the Flemish Indoor Environment Decree of 11/6/2014. Further investigation is needed to identify other international and national benchmark values;
- Similar to in-situ measurements for chemical substances, the timing and location of the in-situ measurements is very important in case of biological agents as well;
- While the field studies analysed did not elaborate in detail on addressing moisture and mould issues during design stage and maintenance, they are understood to be crucial project phases to prevent or remediate moisture and mould problems.

1.4.5. RESILIENCE TO CLIMATE CHANGE (MACRO-OBJECTIVE B5)

→ **Key factors to consider – Thermal tolerances**

- There is a very strong link with thermal comfort. Hence, the tools, methodologies and indicators are similar to the ones typically used for thermal comfort. The main difference is the use of weather data sets to simulate future scenarios (e.g. 2030, 2050 or 2080);
- There is a large dependency on availability of this future climate data. It has to be further investigated to which extent future climate data, comparable to the UKCP09 and CIBSE data-sets in the UK, is also available for other European regions;
- An alternative could be to use historic weather data to represent future conditions (as was the case in the Knowledge for Climate field study). However, the probabilistic approach of the UKCP09 and CIBSE data series are likely to provide a more stable and reliable basis for the simulations;
- Simulation software used are dynamic simulation tools (e.g. EnergyPlus). In other words, tools that can use alternative weather files for the calculations. It has to be examined further to which extent steady-state simulation tools can use projected climate data when assessing thermal comfort. It is assumed that this will not cause any issues;
- Two approaches are used regarding thermal comfort: static approach and adaptive approach. The importance of implementing adaptive thermal comfort models, especially in large scale office buildings, are highlighted in climate change impact case studies. Adaptive thermal comfort can be exploited by designers to make buildings more resilient towards climate change by providing opportunities for occupants to make adjustments of their behaviours to suit the changing environment;
- The level of thermal comfort in office buildings differs from the level of thermal comfort that people experience in their homes. This is caused by several factors. Residents have different activity levels than occupants in office building and the activity level can more easily be adapted to the situation.

→ **Key factors to consider – Green infrastructures**

- The BAF, GSF and the green point system are useful to indicate the quantity of greenery and to a certain extent the quality of greenery (by making use of weighting factors);
- They can incentivize building clients, local authorities and/or property developers to implement measures that will have an influence on the future microclimate on the individual building/site;
- None of these indicators really capture the specific impact of “green” measures to the energy consumption or thermal comfort of the building. In order to be able to calculate this, other tools or methodologies are likely required, such as dynamic simulations.

1.4.6. OPTIMISED LIFE CYCLE COST AND VALUE (MACRO-OBJECTIVE B6)

→ **Key factors to consider – Life cycle cost**

- ISO 15686-5 seems to be the key standard, as it is referenced in all field studies analysed;
- LCC can be conducted on building component level (e.g. BREEAM) or on building level (e.g. DGNB);
- The DGNB-certification scheme includes benchmark values for LCC of non-residential buildings;
- There is a need for consistency in assumptions and data entries to enable comparison of scenarios and building projects;
- The desired end-use for the LCC calculation results determine the level of accuracy of the data. Based on the experience of the field studies, the main data gap seems to be cost data related to operation and maintenance;
- LCC analysis is reported to be often too time-demanding or too complex for building actors. The two-step approach developed as part of LCC-data, aims at overcoming this barrier and making LCC analysis more accessible.

→ **Key factors to consider – Value**

- The European Valuation Standards (EVS) of “The European Group of Valuers' Associations” (TEGoVA) have been identified as key references concerning valuation;
- The IMMOVALUE project developed modified property valuation methodologies based on three common approaches to calculate market value (income related, sales comparison and cost approaches). The new approaches reflect energy efficiency and LCC in a more transparent and quantitative way;
- In valuation practice, the lack of data sets limits for a broad application of the modified valuation approaches. In most cases data on energy efficiency, LCC and other sustainability aspects are very vague. Valuers might need support to make them capable to interpret energy benchmarks, results of LCC analyses and other technical characteristics of the building in a correct way;
- For a broad application valuers need reliable databases on reference buildings (comparables) including not only data on building site, rent level and building equipment but also on energy efficiency and various operational cost categories.

1.5. CROSS-CUTTING FINDINGS

Finally, a number of horizontal findings emerged during the analysis, which were cross-cutting among the macro-objectives.

1. Not all the aspects of the macro-objective can easily be expressed in an indicator on building level. Some aspects are more relevant or practical to assess at the level of a space, building components or even at the building product level. Examples:
 - Ventilation rates or indoor air quality are assessed on room-level;
 - LCA and LCC are less complicated to be conducted on building component level than on building level.
2. The building practice is more familiar with certain macro-objective aspects than others, due to a wide range of reasons, such as the lack of existing regulation, common methodology or complexity. As a result, indicators for these aspects might need more effort to implement successfully. Aspects identified as state-of-the-art are:
 - Embodied carbon emissions (B1);
 - Material utility (B2);
 - Moisture and Mould (B4);
 - Thermal tolerance in a future climate (B5);
 - Value (B6).
3. Geographical location is an important factor to consider, as a certain aspect might be common in some Member States but state-of-the-art in other Member States. For instance, building practices in the UK might be more familiar with thermal comfort simulations using future climate projections than in other regions in Europe. Another example: addressing mould and moisture is common practice in Finland but state-of-the-art in Belgium.
4. To respond to the European context, a common framework with the ability to adapt to local context factors might be recommended. To give an example: the Colour Palette of the Skanska Group, which defines generic ambitions but leaves room for Skanska's Business Units to further specify the performance targets and methodologies based on their local context (B1). However, the EPBD and the national/regional EPBD-regulations both demonstrate the advantages and disadvantages of this approach: despite a European-wide framework, the national approaches differ significantly from each other.
5. Indicators that are practical to use, should be coupled to the existing practice as much as possible, to minimize additional efforts and skills needed to assess these indicators. This can relate both to existing methodologies/tools, or existing regulations and might require to target specific actors, design phases or building components. Examples:
 - Embodied carbon calculations that are coupled to common contractor tools such as cost estimations, Bill of Quantities (BoQ) or Building Information Modelling (BIM) (B1);
 - Embodied carbon calculations targeted to building structures can be more easily embedded in the practice of the structural engineer (B1);
 - Certification schemes link to the existing EPBD regulation for their operational carbon emission targets (B1).
6. A step-wise approach is identified in a number of field studies. This can be a good approach to introduce "new" indicators in the building practice. Examples identified:

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- In a first step, perform an assessment without quantitative targets. Only in a second step, quantitative targets or benchmarks are defined e.g. carbon footprint calculations in Skanska's practice;
 - Use generic data with the option to apply specific data when available e.g. the level 1 and level 2 LCC databases.
7. Indicators and associated calculation methodologies can have a wide range in scope, in particular with regards to the life cycle stages, the building components or use categories considered. Examples:
- Carbon footprint calculations, LCA or LCC rarely include all life cycle stages (production, construction, in-use and end-of-life);
 - Carbon footprint calculations can be performed on the building structure only, or incorporate other building components such as facades or technical installations;
 - Operational carbon calculations cover energy used for heating, cooling, domestic hot water and auxiliary services but not always energy used for lighting and rarely energy used for processes or electrical applications.

To respond to this, the scope of the indicator could be made more transparent. Another approach could be to compose indicators with a modular nature. The initial scope can be further extended with additional building components or life cycle stage to be considered.

CHAPTER 1 INTRODUCTION

This document represents the final report of the study *“Analysis of field studies to support the identification of options for building resource efficiency performance indicators”*. The study is commissioned by Directorate B – Unit 5 of the Joint Research Centre (JRCs) of the European Commission. The Flemish Institute for Technological Studies from Belgium (VITO) has lead this study in collaboration with engineering firm ALTO from France and the university KU Leuven (KUL) from Belgium. The study started in November 2015 and ended in August 2016.

1.1. BACKGROUND: RESOURCE EFFICIENT BUILDINGS (REB) STUDY

1.1.1. POLICY BACKGROUND

The European Commission adopted the Communication on Resource Efficiency Opportunities in the Green Building Sector in 2014 (COM (2014) 445)[EC, 2014], which describes the aim to enlarge the scope of “sustainable” or “green” buildings. The main objective of that initiative is to promote a more efficient use of resources consumed by new and renovated commercial, residential and public buildings and to reduce their overall environmental impacts throughout the full life cycle. To support this development, reliable, comparable and affordable data, methods and tools are needed, however these are still lacking to a certain extent today. This situation results in an absence of guidance on how to incorporate environmental considerations in purchasing decisions.

1.1.2. ASSESSMENT FRAMEWORK WITH CORE INDICATORS

The main objective of the Communication on Resource Efficiency Opportunities in the Green Building Sector (COM (2014) 445) is to influence decision-making along the life cycle of buildings by providing relevant and comparable information regarding their environmental performance. This will be done by developing an assessment framework with core indicators. The assessment framework can be used on its own or as a module next to other indicators in existing or future certification schemes (commercial or public). This work on the development of the assessment framework with core indicators (the “Resource Efficient Buildings” study or REB-study) is led by IPTS. It started in January 2015 and will run for 30 months.

This common framework for resource efficiency assessment in the building sector consists of four work Packages (see Figure 2: Work Package structure of the REB-study):

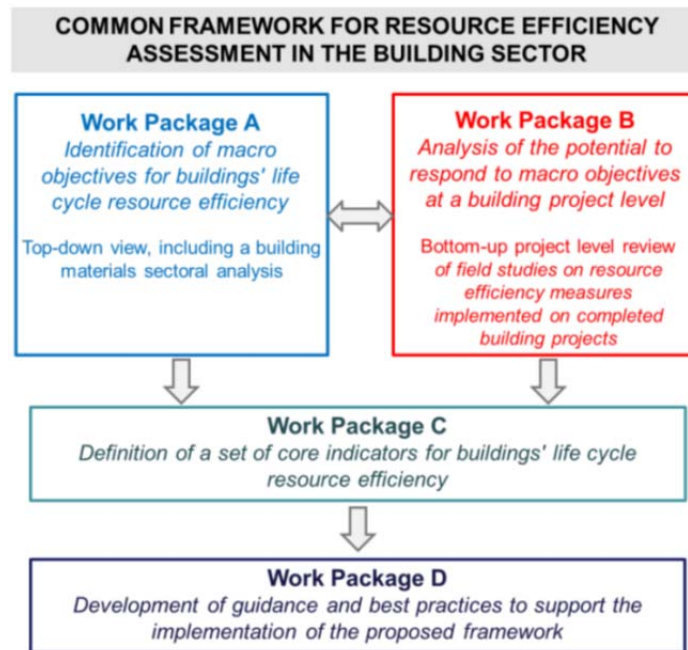


Figure 2: Work Package structure of the REB-study

1. **Work Package A:** Identification of macro-objectives for buildings' life cycle resource efficiency;
2. **Work Package B:** Analysis of the potential to respond to macro-objectives at a building project level;
3. **Work Package C:** Definition of a set of core indicators for buildings' life cycle resource efficiency;
4. **Work Package D:** Development of guidance and best practices to support the implementation of the proposed framework.

More information on the REB-study is available on the project's website:

http://susproc.jrc.ec.europa.eu/Efficient_Buildings/

1.2. WORK PACKAGE B – IMPLEMENTATION OF MACRO OBJECTIVES AT A BUILDING PROJECT LEVEL

In December 2015, the IPTS finalised Working Paper 1 on macro-objectives²⁷, which concluded Work Package A [JRC, 2015]. With this paper, the JRC identified a final set of macro-objectives that either directly address life cycle environmental performance of buildings or relate to quality, performance and value creation.

The macro-objectives paper provided the starting point for Work Package B. The aim of work package B of the study was 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. Therefore, Work Package B identified indicators that can be used at project level to measure the performance of homes and offices against the six macro-objectives identified to be taken forward at a building level (work packages B and C). This 'bottom up' analysis ensured that there was a practical link between the indicators and

²⁷ Full title: Identifying macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings.

the 'top down' perspective of the macro-objectives - a key aspect that was highlighted in discussions within the Steering Group of the REB-study (SG1). The outcome of work package B is Working Paper 2. In July 2016, the JRC published the draft of this document, including summary findings and indicator proposals. This report has been prepared by the JRC with input from VITO, ALTO and KUL and will feed into Work Packages C and D.

The concepts “macro-objectives” and “performance indicator” are further discussed in detail in section 2.1 of this deliverable report.

1.2.1. ANALYSIS OF FIELD STUDIES

The study that is carried out by VITO, ALTO and KUL provides the supporting work for Work Package B. Subject of the study is the analysis of field studies to support the identification of options for building resource efficiency performance indicators (this deliverable report will refer to this study as the “field-studies-project”).

The main objectives of the field-studies-project will be threefold:

1. To identify the project processes, technical data and evaluation tools that were used to translate specific macro-objectives into meaningful and practical performance improvements at the building project level;
2. To identify the options available for indicators at building project level to assess specific performance improvements, including the related functional unit, midpoint impact categories and data sources;
3. To identify lessons learned regarding the (un)successful translation of specific macro-objectives into performance improvements at the project level, including consideration of the role of the project actors, analytical tools, performance evaluation/monitoring tools and verification systems.

The overall goal of the analysis of the field studies is to investigate how these macro-objectives could be implemented in practice at building project level and which indicators could be used for this purpose. The workplan is presented in Figure 3.

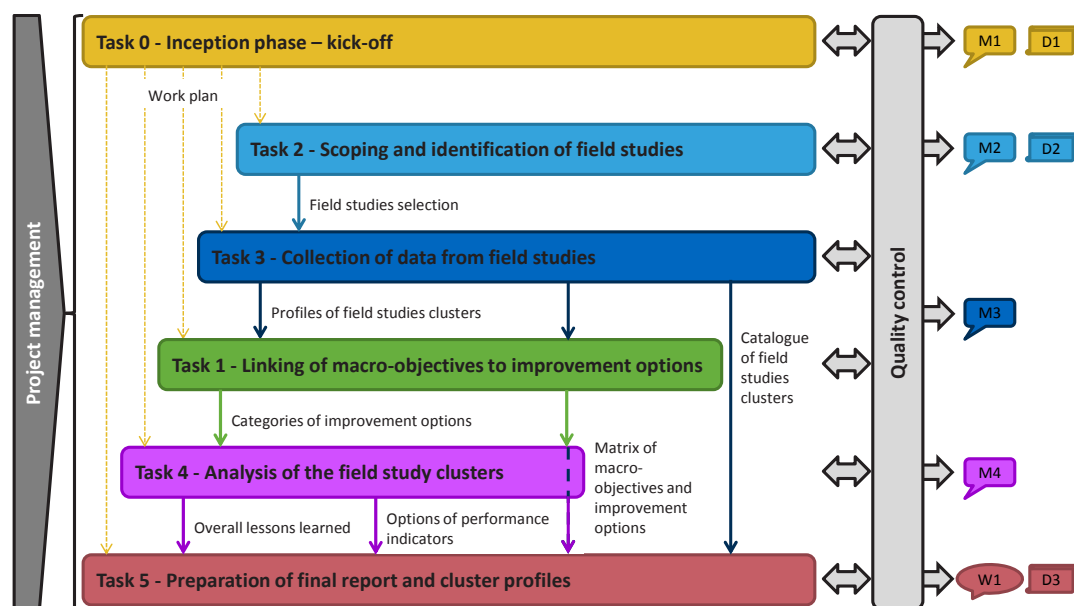


Figure 3: Workplan of the supporting work for Work Package B – analysis of field studies

1.2.2. STRUCTURE OF THIS REPORT

In chapter 1, an overall introduction is provided to the REB-study, which is carried out by the JRC, and the supporting work for Work Package B, which is executed by VITO, ALTO and KUL.

In chapter 2, the objectives, scope and methodology of the analysis of field studies are described. Concepts essential for the study (such as macro-objective, indicator, field study, cross-check) are clarified in this chapter.

In chapter 3, the outcome of the analysis is presented. For each field study, the following information is provided: background and context to the field study, translation of the macro-objectives into practice, indicators used to measure performance improvements and implementation experience regarding implementation experience. In-depth information of the field studies and cross-checks is included in Annex 1 – Catalogue of field studies and Annex 2 – Cross-checks.

In chapter 4, the key findings of the analysis are summarised. For each macro-objective, the following topics are addressed: improvement options; tools, methodologies and standards; data requirements; processes and actors; indicator options and inventory of lessons learned. In the next chapter, chapter 5, cross-cutting findings among the six macro-objectives are discussed.

Finally, the report is concluded in chapter, which includes recommendations for the formulation of indicator proposals.

CHAPTER 2 METHODOLOGY

2.1. AIMS AND OBJECTIVES

2.1.1. MACRO-OBJECTIVES

The JRC identified six macro-objectives as a conclusion of Work Package A. The six macro-objectives focus on the building level and are grouped under two headings - 'life cycle environmental performance' and 'quality, performance and value' [JRC, 2015]. An overview of the macro-objectives is provided in Table 2.

Table 2: Overview of macro objectives and aspects covered [JRC, 2015]

| Life cycle environmental performance | |
|---|---|
| <i>Macro-objective</i> | <i>Aspects covered</i> |
| B1: Reduction of greenhouse gas (GHG) emissions from building life cycle energy use | <ul style="list-style-type: none"> - Operational carbon emissions - Embodied carbon emissions |
| B2: Resource efficient material life cycles | <ul style="list-style-type: none"> - Lean design - Circular flows - Material utility - Environmental impact |
| B3: Efficient use of water resources | <ul style="list-style-type: none"> - Water efficiency - Water scarcity |
| Quality, performance and value | |
| <i>Macro-objective</i> | <i>Aspects covered</i> |
| B4: Healthy and comfortable spaces | <ul style="list-style-type: none"> - Exposure to hazardous substances – ventilation intake air - Exposure to hazardous substances – materials emissions - Exposure to hazardous substances – (de)construction of building components - Moisture and mould |
| B5: Resilience to climate change | <ul style="list-style-type: none"> - Green infrastructures - Thermal tolerance |
| B6: Optimised life cycle cost and value | <ul style="list-style-type: none"> - LCC - Value |

2.1.2. PERFORMANCE INDICATORS

→ 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.

It is important to stress that the aim of the analysis is to identify indicators as much as possible on the level of the macro-objective or indicated sub-aspects on the one hand and the building level on the other hand. For instance, in the case of operational carbon emissions, this translates to focusing on indicators such as primary energy consumption or operational carbon emissions and to a lesser extent on individual U-values of building components (e.g. wall, floor, roof or windows).

→ Defining what makes a suitable indicator

The 2014 Communication on Resource Efficiency Opportunities in the Building Sector – COM 445 (2014)²⁸, 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 3: 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

²⁸ Decision No 445/2014/EU of the European Parliament and of the Council of 16 April 2014 establishing a Union action for the European Capitals of Culture for the years 2020 to 2033 and repealing Decision No 1622/2006/EC

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 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:

- iii) clients/design teams *and*
- iv) 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.

2.2. SCOPE AND DEFINITION

2.2.1. BUILDING TYPES AND PROJECTS

The scope of the study to focus on residential and office buildings [JRC, 2015]. 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.

2.2.2. 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 4 identifies a typical ordering these stages, with reference to the RIBA (Royal Institute of British Architects) Plan of Work (2013) ²⁹.

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 4: 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
6. In-use
Includes: Occupation, operation, maintenance, repair, refurbishment

²⁹ RIBA, *Plan of work 2013*, <https://www.ribaplanofwork.com/>

| |
|--|
| <p><i>Key phases:</i> Post occupancy evaluation, performance monitoring, building life cycle management plan</p> <p>7. Refurbishment</p> <p><i>Includes:</i> See stages 1-5 (according to the scale of the works)</p> <p>8. End-of-life</p> <p><i>Includes:</i> tendering procedure/bidding phase, pre-demolition inventory check</p> <p><i>Key phases:</i> Building disassembly, component and material reuse/recycling</p> |
|--|

2.2.3. 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 4 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.

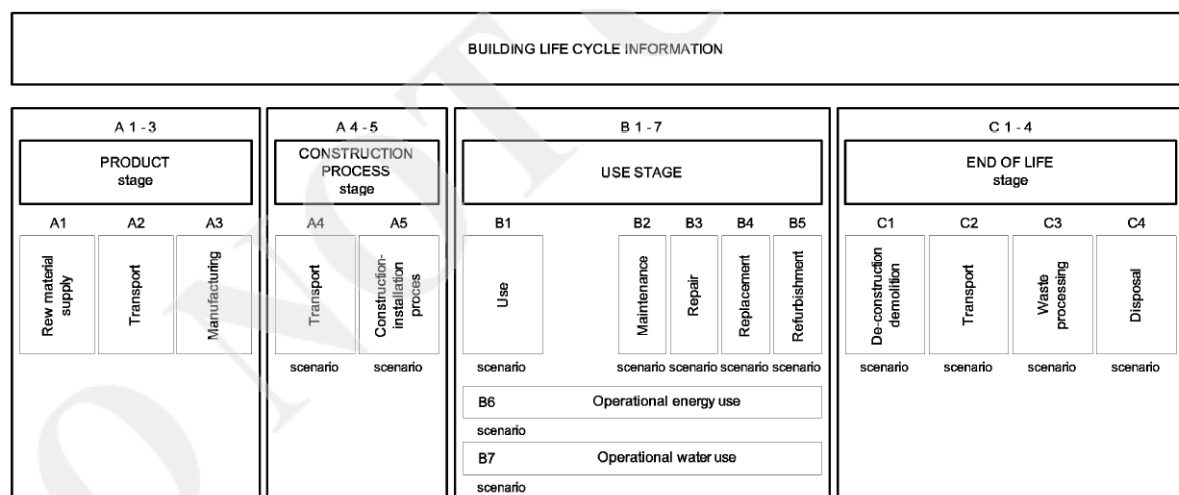


Figure 4: Scope of building life cycle stages to be considered. Source: CEN (2011) Methodology

2.2.4. DEFINITION OF FIELD STUDIES

For the purpose of this study a field study is defined as follows.

Definition of a 'field study'

In the context of this study field studies are understood to be **monitoring and evaluation studies encompassing a range of buildings, either new-build or renovation, where major environmental improvements have been made.** The 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 are expected to provide primary evidence as follows:

- Professional experience at project level of setting performance requirements and using indicators;

- Technical research at building level to identify methods for measuring/monitoring performance.

Selected field studies have addressed specific relevant technical aspects of one or more of the macro-objectives. The analysis will focus on implementation experience at project level. This could relate to the use of targets, benchmarks or indicators of project performance, together with the specific related sets of improvement measures. It will also consider project processes, drivers and responsibilities within the design team.

Some of the field studies draw upon monitoring and testing in the field e.g. Indoor Air Quality (IAQ) testing post-completion/during occupation. In these cases the nature of the field experience analysed is slightly different. The focus will be on findings that guide the design/specification of robust monitoring and testing regimes instead of aforementioned implementation experience during the design and construction of building projects.

The identification of the field studies has taken into account, as far as possible, relevant influences such as different professional and regulatory contexts; building typologies, forms and ages; as well as possible geographical and cultural variations. The scope and factors to address in the selection of field studies are as follows:

1. Building-related factors

- *Completed projects with implemented improvements*: The projects are completed and have resulted in a measured improvement compared to a baseline/reference building³⁰;
- *Building typology*: Implementation experience for offices and homes, covering new-build projects and major/deep renovation projects for both typologies;
- *Building form*: For both offices and homes the form of the building may be of relevance to some of the macro-objectives *for example, according to evidence more compact forms of housing use less energy for space heating and less construction materials*;
- *Building age*: This could be a factor to consider for renovation field studies, as it may influence the extent and nature of the works;
- *Market segment*: The target market segment for the building. For offices, a distinction should be made between 'prime' office space, as well as Category A and B fit out (or equivalents in the local market). For housing, this could be with reference to socio-demographics and/or pricing in the market.

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

- *Climate zones*: Implementation experience across the three broad EU climate zones and their boundary conditions, as identified by the JRC (*see the IMPRO Housing report*³¹);
- *Construction cultures*: Implementation experience across several distinct EU 'construction cultures', which could include consideration of distinct forms of construction. Examples of distinct construction cultures are: *concrete panel-form types of housing in Eastern Europe versus concrete structure/masonry in-fill apartments in Spain and masonry or wooden framed detached/semi-detached houses in the UK*.

3. Market factors (*relevant in particular to macro-objective B6: LCC and value*)

³⁰ We could include some examples where a problem/barrier occurred related to the management process or tools used and hence did not lead to any improvement. This could provide valuable lessons for the indicator development process.

³¹ Uihlein A., Nemry F. et al, Environmental Improvement Potentials of Residential Buildings (IMPRO-Building), EC JRC-IPTS, 2008. Available at: <http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=1744>

- *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 and Design, Build, Finance and Maintain).

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

- *Building permit requirements in Member States*: Instances in which requirements are imposed by the building control and/or planning systems. This will provide experience of mainstream implementation and the responses of the property market;
- *Field studies carried out by collaborative EU projects*: Instances in which ‘action research’ has been carried out by professional project partners (e.g. construction research institutes, construction companies, building owners) involving application of tools/methodologies to live building projects. Project partners in these instances are anticipated to be more willing to learn and overcome barriers;
- *Private or public sector buildings and portfolios*: Instances in which construction companies, private property asset managers and public asset managers have gained implementation experience in developing/using specific indicators across a range of offices or homes. This is anticipated to provide experience of mainstream and/or front runner implementation;
- *Assessment according to specific criteria/indicators in a building scheme/tool*: Instances where a criteria or indicators from an existing scheme that complements/supports one of the macro-objectives has been applied to many buildings. This could include certification scheme criteria (e.g. HQE, DGNB) and reporting tool indicators (e.g. GRESB, Finland BPis).

2.2.5. SELECTION OF FIELD STUDIES

The outcome is a selection of 19 field studies and 12 cross-checks that are put forward for further analysis by VITO and ALTO. The selection has been made for each of the six macro-objectives.

The following key priorities were taken into account during the selection process:

- Coverage of each (identified aspect of the) macro-objective;
- Experience of real-life practice, in particular assessment schemes or building permit requirements.

Furthermore, particular attention has been made to the scope and factors to consider described in section 2.2.4 of this report.

The selection of field study and cross-check evidence has been compiled based on the following main sources:

- Actual building and masterplan projects of ALTO, certified with BREEAM, DGNB, HQE and LEED. Examples: ZENORA offices;
- Evaluation studies of VITO focusing on relevant aspects of the macro-objectives identified. Examples: Ghandi/Hoogbouwplein (material utility), Renovair (Indoor Air Quality);
- Studies based on literature and information from stakeholders gathered to date by JRC. Examples: Skanska plc.

→ 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.

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 revisions of a certification scheme.

Table 3: Project of ALTO Ingénierie with indication of the certification scheme used and particular version applied

| Project | Certification Manual / Level Achieved | Energy Label Or Other environmental aspect |
|-----------------|---|---|
| CBK II | HQE International v2011 / - Level Exceptional BREEAM International v2009 Issue 1.1 / Level Excellent DGNB pilot NOA10 v2012 / Level Silver | |
| LA MARSEILLAISE | HQE v2011 updated 2012/ - Level Excellent Written 2013 because the manual applicable in 2013 has been considered LEED v3 2009 / Level Gold | |
| ZENORA (NODA) | HQE v2008 Offices / Level Exceptional BREEAM International v2009 Issue 1.1 / Level Outstanding | BBC Effinergie (RT 2005) HQE Performance |
| MACDONALD | HABITAT & ENVIRONNEMENT millésime 2008 updated 2009/ | BBC Effinergie (RT 2005) Plan Climat Paris |

| | Level | PROFILE | A | AND |
|-------------------|---|---------|---|--|
| | PERFORMANCE | | | |
| EULER | HQE Renovation v2010 | | | BBC Effinergie renovation (RT 2005 existant) |
| | BREEAM International v2009 | | | |
| | Issue 1.1 / Level Very Good | | | |
| | LEED v3 2009 / Level Gold | | | |
| LAFFITE LAFAYETTE | HQE Renovation v2010 | | | BBC Effinergie renovation (RT 2005 existant) |
| MEDERIC | HQE Renovation v2010 | | | BBC Effinergie renovation (RT 2005 existant) |
| | BREEAM International v2009 | | | |
| | Issue 1.1 / Level Very Good | | | |
| | BREEAM In-Use International v2015 / Level Excellent | | | |

2.2.6. SCREENING, DATA COLLECTION AND FRAMEWORK FOR ANALYSIS

The aim of the field studies analysis was to investigate how the six macro-objectives are translated into meaningful and practical performance improvements in a real-life building project. These performance improvements relate to environmental performance improvements or improvements of quality and value of the building.

The analysis was conducted in two steps. In the first step, potential study objects were screened with the outcome a final selection of field studies and cross-checks. In the second step, data was collected for each field study. The objective of this data collection was to identify the targets, benchmarks or indicators and the technical data, methodologies and evaluation tools in these field studies that were used to monitor and achieve these performance improvements. It also considered project processes, drivers and responsibilities within the design team.

More specifically, for each field study the following aspects will be investigated:

- The process by which the **improvement options** were identified and chosen, what the options were and how they were then integrated into the building specifications. In particular the targets, benchmarks or indicators that were used as evaluation criteria for these improvement options;
- The methodologies, tools, data sources and standards used by the building design team and main construction contractor to successfully **implement and monitor** the performance improvement options during the **different stages** of the building (such as design stage, construction, use stage);
- The roles and responsibilities of the **different actors** within the project in implementing the improvement options, and success factors in ensuring their engagement in implementation;
- The **interrelationships and trade-offs** between on the one hand (aspects of) the macro-objectives (environmental performance versus performance, quality and value) and on the other hand the life cycle stages (product, construction, use and end-of-life phases of the building(s)).

Therefore, the three research questions are as follows:

4. How has the specific macro-objective been translated into action at project level?

5. What indicators were used to measure the performance improvement(s) and what is the associated methodology for quantification?
6. Which lessons can be learnt from the experience of measuring and verifying the performance improvement(s)?

Chapter 3 summarises the result of the analysis for each field study. The detailed analysis is provided in ANNEX 1 Catalogue of field studies.

2.2.7. USE OF SUPPLEMENTARY “CROSS-CHECK” EVIDENCE

The goal of these cross-checks is to provide an additional layer of technical evidence. The cross-check evidence will ensure that findings from the field studies are analysed within the broader professional, regulatory and technical context. In addition, it will ensure that any gaps in the technical scope and coverage of the field studies are addressed. They will provide the JRC with a framework for a high-level comparison.

The following sources can be interpreted as cross-checks:

- Synthesis reports of professional experience and technical research relating to a specific performance aspect;
- Findings from public and private sector initiatives setting performance requirements;
- Lessons from harmonisation initiatives.

An overview of the cross-check studies analysed by VITO and ALTO are included in ANNEX 2 Cross-checks.

CHAPTER 3 DATA COLLECTION AND ANALYSIS OF THE FIELD STUDIES

3.1. MAC DONALD MASTERPLAN

Boulevard Mac Donald is an urban redevelopment masterplan in the north of Paris, France. It centres around the rehabilitation of the old Mac Donald warehouses. It consists of 15 multi-family apartment buildings. A kindergarten has been integrated into one building and shops are located on the ground floor. Another 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 the 15 building units. The buildings had to achieve the following certifications: “Habitat & Environment (H&E)”³² and “Bâtiment Basse Consommation (BBC)”³³.

Table 4: 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 ² SHON | In-use |
| N6 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 60 apartment units – 4 544m ² SHON | In-use |
| S6 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 43 apartment units – 3 749 m ² SHON | In-use |
| S7 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 82 apartment units – 7 355m ² SHON | In-use |
| E1 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 147 apartment units – 4 174m ² SHON | In-use |
| N1 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 45 apartment units – 5 041m ² SHON | In-use |
| N2 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 90 apartment units – 5 905m ² SHON | In-use |
| S1 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 50 apartment units – 3 558m ² SHON | In-use |
| S2 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 138 apartment units – 8 021m ² SHON | In-use |
| O1 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 78 apartment units – 5 910m ² SHON | In-use |
| N3 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 84 apartment units – 6 859m ² SHON | In-use |
| N4 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 61 apartment units – 4 727m ² SHON | In-use |
| S3 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 128 apartment units – 3 458m ² SHON | In-use |
| S4 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 33 apartment units – 2 675m ² SHON | In-use |

³² Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

³³ BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

| | | | | | |
|----|-------------------------------|---------------------------------|-----------|--|--------|
| S5 | Central-Europe, Paris (FR) | Residential: Apartment block | New-build | 42 apartment units – 3 279m ² SHON | In-use |
|----|-------------------------------|---------------------------------|-----------|--|--------|

3.1.1. MACDONALD MASTERPLAN: B1

→ 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:* Masterplan requirements implied BBC Label Effinergie of each building: Cep < 65 kWh/m².year and airtightness <1m³/(h.m²).

The Cep is derived from the French energy regulation (Cep < Cep reference)³⁴.

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 also defined in the masterplan:

- 25% of total energy consumption covered by renewable energy;
- 30% of energy consumption for domestic hot water covered by renewable energy.

→ How performance improvements were measured

Potential indicators identified:

- Total primary energy consumption [kWh/m².year]
- Reduction of energy consumption [%]

Supporting indicators:

- Airtightness [m³/m².h]

→ 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 the French Thermal Regulation 2005 – was provided by ALTO Ingénierie regarding energy consumption optimization to fulfill the masterplan requirements and at the same time support the designers in finding solutions that would meet the initial targets as much as possible. The required percentage of glazing per façade was not met.

The integration of new buildings alongside the existing 600 meter long building was a challenge in terms of structure and airtightness. Compromises had to be found to ensure BBC labelling and

³⁴ Cep: Primary energy consumption (Consommation Energie primaire), including energy for heating, cooling, domestic hot water, electricity for pumps and fans, and lighting facilities, expressed in kWh/m²/year.

conservation of the existing structure. As a result, light-weight façades were chosen for some buildings to reduce the building energy loads as much as possible.

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, it is very important that the architect and responsible contractor inspect the quality of the work in progress very regularly considering the fact that some modifications may occur during construction.

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

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

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

In Paris, checks from CERQUAL35 - the HQE certification body – are getting stricter and stricter. This is not the case everywhere in France. As a result, the as-built construction may not always be at the same level of quality as the design. This third party check is important to ensure environmental performance.

3.1.2. MAC DONALD MASTERPLAN: B3

→ Translation of the macro-objective into actions and improvements for buildings in the cluster

ALTO Ingénierie was the environmental consultant for the 15 building units. The buildings had to achieve the following certifications: “*Habitat & Environment (H&E)*”³⁶ and “*Bâtiment Basse Energie (BBC)*”³⁷. The following areas of focus for improvement were identified.

Reducing the consumption of potable water for sanitary use

The residential certification lead by CERQUAL³⁸ does not specify a limitation of water consumption per flat/home per day or year or person. As a result only a 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;
- Pressure of 3 bars (NF EN 1567);
- Sanitary appliances classified ECAU / E1C2³⁹;

35 CERQUAL is the certification body in France for the BBC label

³⁶ Habitat & Environnement certification, <http://www.qualite-logement.org/certification-et-labels/connaitre-les-certifications-de-qualite-neuf/autres-certifications/qualitel-habitat-environnement.html>

³⁷ BBC: Bâtiment Basse Consommation (Low Energy Building): Standards with related label for Low Energy Buildings in France. <http://www.norme-bbc.fr/>

³⁸ CERQUAL is a French certification body for low energy building certifications in France

- Showers and bathtubs with thermostatic mixing valve;
- Individual meters in each apartment.

The certification scheme emphasizes the quality framed by French rate ECAU³⁹. Class “E” is linked to the water flow rate (while C, A and U relate to ergonomic, acoustic and durability requirements respectively). Class “E” is split into the following performance levels:

- E0: ($9 \text{ l/min} \leq q < 12 \text{ l/min}$);
- E1: ($12 \text{ l/min} \leq q < 16 \text{ l/min}$);
- E2: ($16 \text{ l/min} \leq q < 20 \text{ l/min}$);
- E3: ($20 \text{ l/min} \leq q < 25 \text{ l/min}$) – Minimum for bath;
- E4: ($25 \text{ l/min} \leq q$).

Additionally, criterion C2 requires that sanitary appliance be equipped with an “economy position”, which implies that the flow rate has to correspond with category C2 (flow rate between 0,11L/s and 0,14 L/s).

→ How performance improvements were measured

Potential indicators identified:

- o flow rates per sanitary appliance [l/min];
- o classification of sanitary appliances [rating e.g. ECAU³⁹ in France];
- o Individual meters in individual dwelling units.

→ Implementation experience of practitioners involved with delivery of the improvements

Achieving H&E (HQE) certification was a priority from several standpoints: 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 use the data received directly 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.

3.2. ECO-LIFE

3.2.1. 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 CO₂-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

³⁹ CSTB (2016) *Le classement ECAU* [online], available at <http://evaluation.cstb.fr/classement/ecau/> [20/5/2016]

commissioned by the social housing company “Goedkope Woning” in Kortrijk. Both the apartment blocks and the single family houses are part of the social housing. Phases 1 to 3 of the Venning District are monitored by the University of Ghent. The 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 the monitoring of energy consumption and indoor environmental parameters (such as indoor temperature, humidity and CO₂ level).

The study also 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 the study, discussions have been held with the residents to find out how optimal results can be achieved, and similar discussions will also be held after the project is completed.



Figure 5: Overview of the Venning neighbourhood design (Source: Buroll & ARCHI+I)

Table 5: 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

3.2.2. 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 calculations and measurement campaigns 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. Stricter E-level and K-levels, compared to the 2015 Flemish EPBD standard, are set as the main targets for new and renovated buildings, being E25 – E30 and K15 for both new apartments and houses while E30 – E37 and K20 for renovated houses. In addition, the Belgian Passive House Requirement is also used as the general guideline during the building design stage for some specific targets, e.g. airtightness $\leq n50 - 0.6/h$.

The 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.

3.2.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The main and supporting indicators are identified as follows:

- Carbon emission [$tCO_2CO_2eqCO_2eq$];
- Primary energy use [kWh/m^2year] or [E-level];
- Net energy demand [kWh/m^2year];
- Thermal insulation level [K-level];
- Airtightness [h^{-1}] at 50 Pa.

Primary energy use, carbon emissions (product of primary energy use and emission factor), net energy demand and thermal insulation level are outputs from Flemish EPBD tools, and an airtightness is required according to the passive house standard. The scope of most indicators studied is at building use stage while only that of thermal insulation level is studied at 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_2 -equivalents and the balancing period is one year. This means that the net amount of CO_2 -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 others, but the overall target remains carbon neutrality. Therefore, carbon emissions are not evaluated at building level in this project, but are calculated at the district level and take 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. This has a significant impact on the results and the scope of operational primary energy use, but it can be measured and verified with metering data.

Another finding is that the type of ventilation system has a 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 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). 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. Differences between these tests could also be explained by the fact that different people conducted the measurements.

Energy performance and insulation level are inherently linked, and it is common to see that well insulated buildings theoretically have a better energy performance. In addition, it is also obvious that insulation level and airtightness are usually linked: 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 thermal comfort and indoor climate (temperature, humidity, lighting, etc.).

3.2.4. 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. No CO₂ targets are set at the individual building level, instead the goal is a net energy balance at the district level between generation and consumption in the use phase. This reflects the EU ambition of 'nearly zero energy buildings', with the associated range of different definitions.

To validate the actual building performance, actual energy consumption is measured and analyzed by researchers from the University of Ghent with the support of clients and inhabitants. Designed energy demand is rather low, but the gap shows that energy demand varies strongly between the dwellings. The comparison between actual and designed energy use for space heating and domestic hot water in Zone 1 are shown in the figures below. Figure 6 presents the actual heat use of each dwelling in function of the normalised designed heat use of the new built dwelling. Figure 7 shows the actual and calculated heat use of the existing dwellings before the refurbishment or replacement process took place.

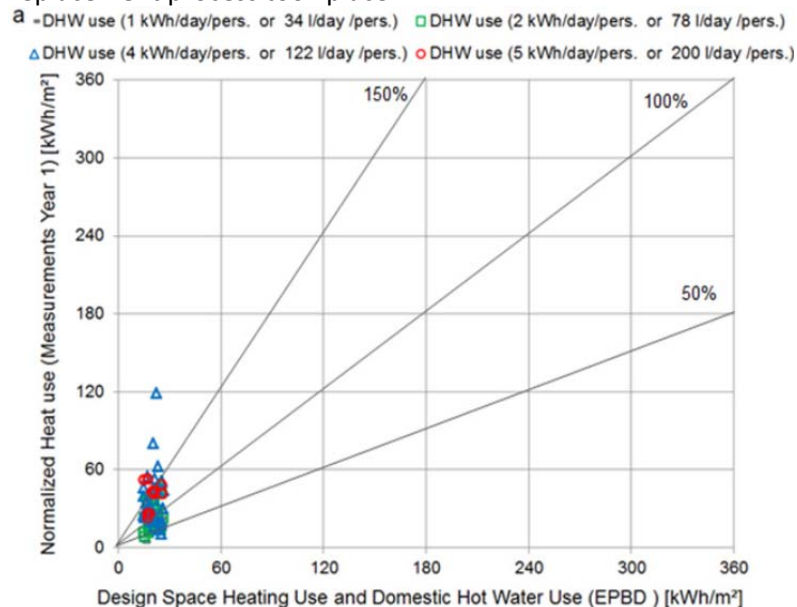


Figure 6: Design energy use for space heating and domestic hot water (new built dwellings)

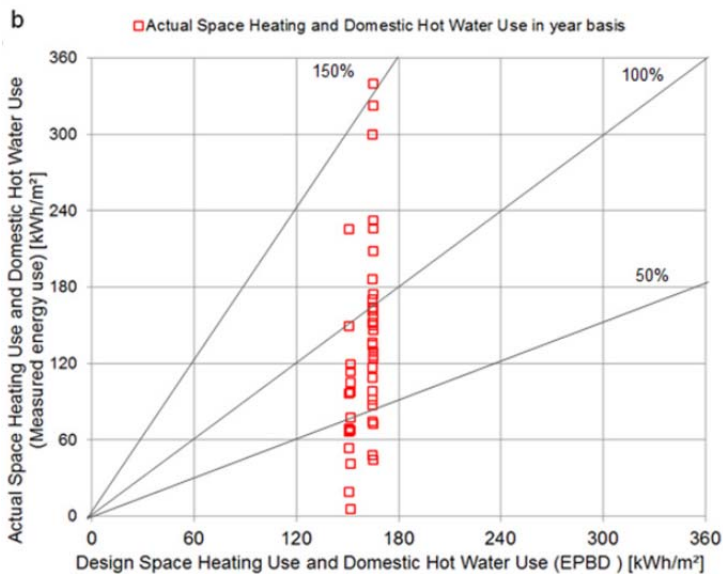


Figure 7: Actual energy use for space heating and domestic hot water (existing dwellings before refurbishment)

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 the EPBD tool, the resulting E-level can alter by different default settings and primary energy conversion factors in the 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, an air-tightness test is required to obtain the passive house certificate in Belgium. Last but not 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 designed and actual operational energy performance. Different tests are conducted in selected buildings, e.g. co-heating tests and airtightness tests. However from the current experience of the researchers, valid practical tests are sometimes difficult to execute due to measurement error or other issues (hard to interpret the results).

3.3. GHANDI/HOOGBOUWPLEIN

3.3.1. BACKGROUND AND CONTEXT TO SELECTION OF THE CLUSTER

The *Mahatma Gandhi 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 way⁴⁰.

Table 6: 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 |

3.3.2. 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 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);

⁴⁰ 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>

- The existing building will be stripped to its load-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).

3.3.3. 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/m² NFA or external environmental cost in €/m² NFA];
- Life cycle environmental impact [kg impact-equivalent/m² NFA or external environmental cost in €/m² NFA];
- Initial financial cost [€/m² NFA];
- Life cycle financial cost [€/m² 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 8).

| | 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 8: Overview of the 23 Design for Change criteria; a breakdown by scale (element, building, neighbourhood) and by theme (interfaces, sub-components, composition) enables 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 impact of each alternative is quantified. The calculation of the initial and life cycle environmental impact (IE and LE, respectively) is based on the Belgian assessment method MMG⁴¹, in line with EN15978⁴² and

⁴¹ 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

the ILCD Handbook⁴³. Within the MMG method, environmental impacts are expressed in individual impact indicators (expressed in kg impact-equivalent/m² net floor area), but also as an aggregated indicator, based on external environmental costing⁴⁴. The calculation of the initial and life cycle financial cost (IF and LF, respectively) is based on the Belgian Science Policy project SuFiQuaD⁴⁵. For the Hoogbouwplein project, (externalised) environmental and financial costs have been projected over time. In Figure 9 and Figure 10 results for different internal wall options – each with an expected lifespan of 15 years in a building with an estimated lifespan 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. Each shows the cumulative increase in costs as the wall element is replaced successive times over a 60 year period.

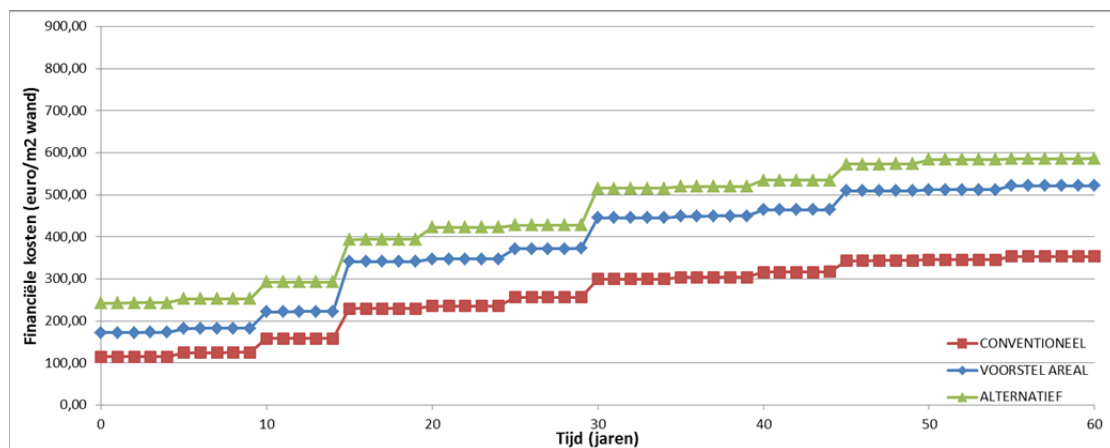


Figure 9: Financial costs in euro per m² of an internal wall over time, with an expected adjustment frequency of 15 years in a building with an estimated life span of 60 years

⁴² CEN (2011), EN 15978 Sustainability assessment of construction works – assessment of environmental performance of buildings – calculation method

⁴³ 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.

⁴⁴ 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>

⁴⁵ 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.

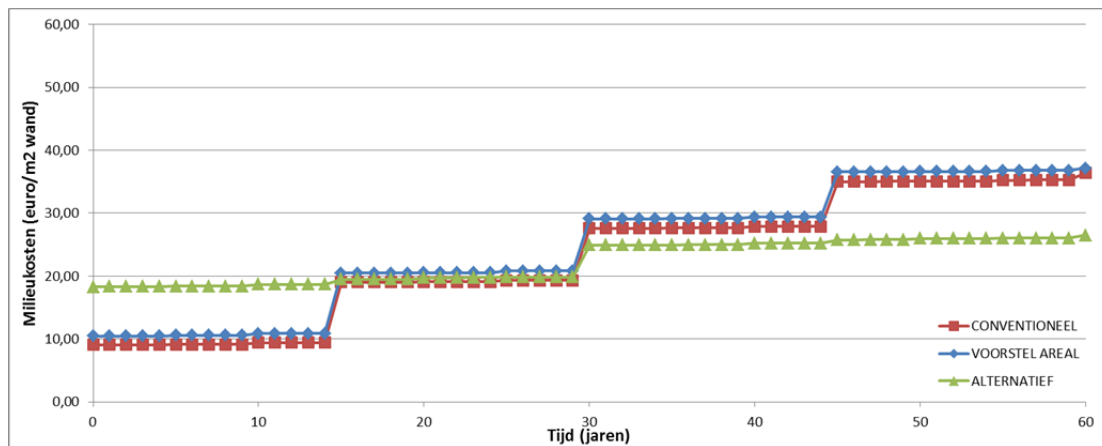


Figure 10: External environmental costs in euro per m² of internal wall over time, with an expected adjustment frequency of 15 years in a building with a estimated life span of 60 years

3.3.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

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 23 Design for Change principles are a synthesis of design principles currently used by 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 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 comparable to a traditional design process. The designers team were also interested to have an objective evaluation of their design choices.

3.4. 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 in France. It is certified according to HQE, BREEAM and HQE performance. The versions used are: HQE construction v2008, BREEAM v 2009 and HQE performance.

Table 7: 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 ² SHON ⁴⁶ | Under construction |
| Tour CBKII | Central-Europe, Luxembourg | Office: high-rise | New-build | 18 storeys 3 basements 26 903m ² 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 ² | In-use |

3.4.1. ALTO OFFICES – NEW-BUILD B1

→ 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)
“*U_{bât}*” represents the (average) heat loss of a building by transmission through the walls (including thermal bridges) and windows expressed in W/m².K. The lower the *U_{bât}*, the better the thermal performance of the building envelope.
- LA MARSEILLAISE: French Thermal Regulation of 2012 (RT 2012)
“*B_{bio factor}*” is a dimensionless number expressed by a number of points calculated using the following relationship:

⁴⁶ *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

Bbio = 2 x (Heating demand and Cooling demand) + 5 x (Artificial lighting needs) in which heating, cooling and lighting demand of the building, are calculated by an hourly dynamic simulation software. Energy consumption by the ventilation system and lighting facilities is based on default values included in the software.

- CBKII: Thermal Regulation from Luxembourg. The “*warmeschutzklasse*” (kWh/m².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 $C_{ep} < C_{ep \text{ reference}}$ (calculation from RT 2005 or RT 2012)⁴⁷
- BREEAM: Reduction of 37% as minimum compared to C_{ep} to get credits required on the project (calculation from RT 2005 or energy performance regulation in Luxembourg)
- BBC Effinergie⁴⁸: $C_{ep} < C_{ep \text{ reference}} - 40\%$ (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: 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 (in accordance with DIN 277 standard): 85'025 m²NFA.

3. Reduction of CO₂ 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

Local Low Zero Carbon (LZC) energy technologies have been installed on ZENORA and CBKII in line with the recommendations of a feasibility study led by an energy specialist. This and this method of supply should result results in more than a 15% reduction in the building's CO₂ emissions according to(not achieved in the project but a feasibility study (although these results have not yet has been measured in the project conducted). Furthermore, in the La Marseillaise project, a percentage of the total energy consumption is covered by on site renewable energy production. An urbanUrban district network linked to marine geothermal energy is used in the project and as a result the percentage is $\geq 1\%$ than required by the LEED certification scheme. CalculationsCalculation are conducted with commercial dynamic simulation software using the ASHRAE 90,1-2007 Appendix G methodology.

→ How performance improvements were measured

Potential indicators identified:

- Operational carbon [kg CO₂eq/m².year]
- Primary energy consumption [kWh/m².year], [%]
- Reduction of energy consumption [%]

Supporting indicators:

⁴⁷ C_{ep} : Conventional energy consumption of a building for heating, cooling, domestic hot water, electricity for pumps and fans, and lighting facilities are expressed in kWh/m² /year in primary energy

⁴⁸ BBC-Effinergie is a French certification for low energy buildings: <http://www.effinergie.org/web/index.php/282-english>

- 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 [$\text{W/m}^2\cdot\text{K}$]
- Airtightness (only for ZENORA and this was not an initial goal – measurements have been conducted by the client at end of work in order to integrate the result into the energy modelling calculation)

→ Implementation experience of practitioners involved with delivery of the improvements

The three projects aimed to receive a high performance score with several certification schemes. From ALTO's experience, achieving those goals was often linked to attaining 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 in this project and was committed to setting 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. The differences between 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. Separate lots created difficulties regarding the certification process.
- LA MARSEILLAISE: Specific presentations were made to the investors to justify the achievement of the project energy goals. This helped the team to make decisions and propose improvements toward achieving those goals. Working with the investors was really beneficial and hopefully this will result in as few modifications as possible during the work on energy aspects.

3.4.2. ALTO OFFICES – NEW BUILD: B2

→ 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 tonnes 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. As a result, they 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. LEED 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. In this way, 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 life span and to design it accordingly. This is linked to environmental product declarations (EPDs), where the expected life span 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, this does not strongly influence building design. Realistically 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 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. The same line of reasoning is applied to other building systems (e.g. lighting). Moreover, the building design anticipated an additional percentage of available power beyond the needs of HVAC aspects and also included extra spaces for cables to permit future adaptation of the building. It should be noted that the involvement of the tenant in the design process 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 greater than 2.75 m;
- Non-bearing, room separating elements can be added, converted, or removed without too much effort while allowing building operation to continue as normal (minimal limitations on operation);
- Non-bearing, room separating elements can be dismantled, and there is a possibility of temporarily storing unnecessary elements;
- Power and media conduits run through easily accessible supply shafts, cable ducts, or false floors and/or the lines are visible;
- Less than 80 % of the capacity of the supply shafts and ductwork for power and media conduits is utilised;

- Waste water removal/supply system's distribution and connections are 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 ($S_{eff} = \text{Usable floor area} / \text{Gross floor area}$) 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_{eff} cannot be maximized without limit. Legal requirements for the size of work areas and trafficked areas must be considered.

Significant environmental impacts

Environmental impacts were in all three 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 ⁴⁹ or FSC ⁵⁰ certified in order to comply to HQE and LEED certification.

BREEAM (CBKII)

A technical study was prepared in the design stage and provides a summary of the MAT 1 calculator, under the framework of the Green Guide⁵¹ 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 and 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 façades).

HQE (all buildings)

Environmental impact was analysed using the French EPD scheme – the FDES (Environmental and Health Declaration) ⁵².

→ 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;

⁴⁹ <http://www.pefc.org>

⁵⁰ <https://ic.fsc.org/en/certification>

⁵¹ <https://www.bre.co.uk/greenguide/podpage.jsp?id=2126>

⁵² <http://www.inies.fr/accueil/>

- Ease and scope of disassembly;

→ **Insight into the environmental impact of components. 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.

The Green Guide and related BREEAM tools are user-friendly. 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 attain 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 certificate⁵³).

Concerning the DGNB criterion linked to the space efficiency factor, this indicator illustrates the initial goal 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 encourage clients to improve this aspect.

3.4.3. ALTO OFFICES – NEW-BUILD AND RENOVATION: B3

→ **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 by 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. In each case, these are related to the distinct requirements of each assessment scheme.

Reduction of water consumption in use stage

During construction, the performance of sanitary appliances had to be verified based on manufacturer's data sheets provided by the contractor. When differences were found compared to the performance assumed in the design stage, calculations were updated. The process of verification was based on multiple certification criteria, which in summary were as follows:

- o 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;
- o BREEAM: The consumption (m³/person/day) of the assessed building is compared to a baseline performance. BREEAM credits are awarded if the consumption value is less than 5,5m³/person/year. Maximum credits can be achieved when consumption is lower than 1,5 m³/person/year;
- o LEED: The consumption (L/person/day) of the assessed building is compared to a baseline performance and is expressed in a % of reduction;
- o DGNB: Limit values are calculated for each project in (m³/year). The target value can be reached with savings from innovative water-saving installations (for example, waterless

⁵³ <http://www.irca.org/en-gb/registration/schemes/Environment/>

urinals), intelligent irrigation strategies, use of greywater and/or use of rainwater. The “water use value” is created by adding the calculated potable water demand and the volume of wastewater. 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 manufacturer’s 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 rainwater, greywater

Strategies to reduce the water demand (rainwater harvesting, greywater harvesting, etc.)

Greywater recycling or rainwater reuse are not necessary to fulfill the HQE water criteria but are used to get the maximum environmental value. According to DGNB, BREEAM and LEED, projects have to specify that these systems are applied. Furthermore, the design team's own calculations may also be required in order to provide the necessary input into the water calculation tools of each of the 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 the case of tour La Marseillaise (imposition on peak rate of runoff and predicted volume of rainwater discharge are 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 included in the BREEAM 2009 calculation tool. DGNB and LEED also consider the reuse of greywater in their calculations (for instance, greywater that is used instead of potable water is subtracted from the water demand). HQE does not include the reuse of greywater in its calculation of water consumption.

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 for new buildings. 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.

→ 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 greywater reuse and rainwater reuse).
- water consumption during construction.

Supporting indicators:

- flow rate of sanitary appliances (l/flush for cisterns, urinals; l/minute for washbasins, showers);
- greywater reused;
- rainwater reused;
- installation of water metering, including sub-metering for building functions with a high water demand.

Various units of measurement and calculation tools are used depending on the certification scheme: % reduction compared to reference value; m³/year (per building); m³/person.year (per occupant).

→ 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 its potential impact. It was found that the design team and contractors are not always aware of how 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 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. A particular advantage of the DGNB calculator was its transparency, where all of the calculations and assumptions behind them were described in the certification scheme manual. By integrating rainwater and greywater reuse into the equation, it is easier to compare water use values from different projects. Other calculators, such the one of BREEAM 2009, use a “black box” approach, which makes it more difficult to understand how the 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 greywater recycling had been withdrawn to save on costs and design complexity but reintegrated again later in the project in order to obtain more credits.

The DGNB calculation tool and accompanying guidelines were straightforward and easy to work with. There is little room left for different interpretations or 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.

3.4.4. ALTO OFFICES – NEW-BUILD AND RENOVATION: B4A**→ Translation of the macro-objective into actions and improvements by buildings in the cluster**

The paragraphs below summarise the areas of focus for improvement identified in relation to the projects. They are related to the distinct requirements of each assessment scheme.

Hazardous substances – ventilation intake

Minimum flow rates of ventilation are required for the office spaces. Different threshold values are used, depending on the certification scheme. They are normalized per occupant. The reference standards are: EN 13779 and EN 15251 for HQE and BREEAM; and the 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 8: Certification scheme ventilation requirements applying to the office buildings

| Scheme criteria | Performance requirements | Buildings |
|---|--|--------------------------|
| HQE 11.1/13.1: ensuring an efficient ventilation | 25 m ³ /h/per in offices spaces (French regulation) as a minimum (base performance level). Higher performance levels have corresponding flow rates. | ALL |
| BREEAM HEA 8: Indoor Air quality | 36 m ³ /h/per in offices spaces | ZENORA CBKII EULER |
| LEED IEQp1-IEQc2 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 ³ /min/per | LA MARSEILLAISE |
| LEED IEQc5 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 |

Hazardous substances – material emissions

DGNB: Indoor TVOC concentrations 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 Table 9. The chemical compounds to be tested for including 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 specifics requirements and the surface depends on the certification scheme and performance to achieve (50% as minimum for HQE and 100% for BREEAM and DGNB).

HQE: Requirements are according to the European directive 2004/42/CE. A French regulation was published on 25 March 2011 regarding mandatory labelling of construction products installed indoors, including 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 a European reference room.

Table 9: Certification scheme product requirements that apply to the ALTO office buildings

| Scheme criteria | Performance requirements | Buildings |
|--|--|--------------------------|
| HQE 2.4/13.2 : 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 |
| BREEAM HEA 9: 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 |
| DGNB Criterion 20: Indoor Air quality | category III of annex B of EN 15251 | CBKII |
| DGNB Criterion 6: 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 |
| LEED IEQc4.1 to 4.4 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 |

→ How performance improvements were measured

Potential indicators identified:

- Ventilation flow rate (m³/hr/person)
- VOCs emission (%)
- Filtration classes of polluted external air

Supporting indicators:

- Temperature;
- Indoor CO₂ (CO₂-sensors for spaces with unpredictable or variable occupancy patterns)

Mould has also been measured 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)/m³.

→ Implementation experience of practitioners involved with delivery of the improvements

Calculations are updated throughout the design process and construction work. This is the certification 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 in line with a European testing methodology. All the projects had difficulties in particular with flooring adhesives, paints and varnishes that were used in internal spaces instead of external spaces as intended (yet they were classified for the two uses by manufacturers). This is because they give off higher VOC

emissions than allowed for internal spaces although they comply with the Decopaint Directive thanks to their double classification.

It is understood that HQE's aim is to encourage the provision of environmental data more than to achieve consistency in the values. Test certificates are not required and VOC performance is often linked to a label or manufacturer's data.

At the present time, BRE accepts eco-labels for products which means that a test carried out according to European methods has not always 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 enters the building.

Furthermore, the measurement conditions were not ideal: carpets as well as crawl spaces and ventilation channels were not cleaned well, windows were opened with the result that external pollution entered the building before the ventilation's commissioning. Measurements have not been conducted yet for CBKII.

3.4.5. ALTO OFFICES — NEW-BUILD AND RENOVATION: B6

→ 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 target performance differs between both certification schemes, and depends on 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 a Life-Cycle Cost (LCC) analysis model to improve design, specification, maintenance and operational 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 life-cycle stages:

- a. Construction
- b. Operation
- c. Maintenance (including planned maintenance as a minimum), 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:

- o Structure
- o Envelope
- o Services
- o Finishings

As a result, LCC has only been applied at building element level as opposed to building level (for both new build and renovated offices).

DGNB Life-cycle costing is a valuable technique that is used for predicting and assessing the cost performance of constructed assets. It is in line with the standard ISO 15686-Part5.

All the costs from project development to construction and handover of the building are defined as acquisition costs. Maintenance and operation costs are determined over a period of 50 years and their net present values are calculated.

Costs are given as a net present value per m² of gross floor area. The DGNB scheme provides benchmarking values and awards credits according to the following values:

- o One credit (minimum score) is awarded if the building achieves a LCC net value < 3.620 [€/m² GFA];
- o ten credits (maximum score) if the LCC net value is < 2.000 [€/m² GFA].

In case of CBK II, nine credits were achieved. The evaluation is performed by comparing the building performance data to comparable buildings.

The following selected cost categories are taken into account when calculating building-related life-cycle costs:

1. Construction costs
2. Occupancy costs
 - a. Operation costs (supply and disposal, cleaning, energy consumption, operation, inspection, and maintenance)
 - b. Maintenance costs
 - c. Dismantling and disposal costs

The following six 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

→ How performance improvements were measured

Potential indicators identified:

- o Net present value [normalized per GFA m²]

Supporting indicators:

- o Building element and component life spans

→ **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 easily accessible to all the project's actors for a number of reasons:

- o The client did not plan for the LCC studies in the contracts;
- o The environmental consultant had difficulties to guide the design team in the completion of studies;
- o The design team had not carried out an LCC before in the context of a design;
- o There was a lack of national databases or common guidelines to support LCC analyses in France.

In practice, the design teams had 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 possessed data on maintenance costs. The main knowledge gaps identified were costs related to the end of life of the building.

Regarding *DGNB*, the necessary expertise was not available within the design team but the methodology was well explained. Default values for maintenance and end of life of the building were available in the manual. As a result, consultants were able to compile data and finalise the study. In the case of CBK II, these default values were effectively used.

In both cases, the certification scheme provided limited support. DGNB was at its pilot version and no tool was available for the LCC calculation. 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.

3.5. 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 work 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).

MEDERIC is also a major refurbishment of a large office building, with the same kind of refurbishment work. 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.

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.

Table 10: 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 ² | In-use |
| Mederick | Central-Europe, Paris (FR) | Office: medium-rise | Refurbishment | 10 storeys; net area 6 619m ² | In-use |
| Laffite Lafayette | Central-Europe, Paris (FR) | Office: medium-rise | Refurbishment | 8 storeys; net area 5 589 m ² | In-use |

3.5.1. ALTO OFFICES – RENOVATION: B1

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

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

The 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 CO₂ emissions

HQE: Calculation of CO₂ emissions. To calculate the operational carbon emissions, primary energy consumption is multiplied by conversion factors provided by CERTIVEA54 (based on ADEME55 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 the recommendations of a feasibility study conducted by an energy specialist. The same study has been done for the Mederick project but no LZC technology has been identified as more advantageous 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)

54 CERTIVEA is the certification body of HQE in France and is affiliated with CSTB

55 ADEME is the French Environmental Agency

→ **How performance improvements were measured**

Potential indicators identified:

- Operational carbon [kg CO₂eq/m².year]
- Primary energy consumption [kWh/m².year];
- Reduction of energy consumption [%].

Supporting indicators:

- Proportion of energy demand covered by renewable energy production [%]
- Net energy demand for cooling [kWh/m².year]
- Thermal insulation level of the building [W/m².K]

→ **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 cases) and achieving a high energy performance.

Project specific lessons learned are the following:

EULER: The client gave higher priority to indoor air quality than to energy performance (which resulted in higher ventilation rates). The energy label was achieved even with this decision.

LAFFITE LAFAYETTE : The certification ambitions were defined 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 designation of a number of spaces that were 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.

3.5.2. ALTO OFFICES – RENOVATION: B2

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

Again, a distinction is made between circular flows 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. More than 96% volume of the façades have been reused. As a result more than 96% of structural elements have been reused. Regarding site construction, a diversion from landfill of 91,3% was reached for a production of 3057 tonnes of waste.

MEDERIC: The building has been designed in order to recognize and encourage the in-situ reuse of existing building façades. More than 89% of façades have been reused. As a result more than 64%

of structural elements have been reused. Regarding site construction, a diversion from landfill of 83% was reached for a production of 1788 tonnes of waste.

LAFFITE LAFAYETTE: Regarding site construction, a diversion from landfill of 88,6% was reached for a production of 2954 tonnes of waste.

As a result, it can be concluded that there are no real challenges on reusing structural elements or façade elements in renovation projects but it must be highlighted that those projects are all located in Paris and are linked to strict regulations regarding architectural conservation. Similarly, diverting wastes from landfill has been relatively easy to achieve but it should be noted 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

This aspect is considered in all three certification schemes used in this cluster. Unfortunately, credits have not been researched for LEED.

BREEAM (EULER): BREEAM's MAT1 calculator is used, under the framework of BRE's Green Guide (the same approach used for 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 the Green Guide's rating scale).

HQE (ALL)

The tools, data and methodologies applied are similar to new-build offices (see section 4.3.1)

→ 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;
- Insight in the environmental impact of components.

→ 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).

3.6. ENSLIC

3.6.1. 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 ⁵⁶. 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 energy savings in the construction and operation of buildings. It started in 01/10/2007 and ended in 31/03/2010.

Table 11: EU buildings analysed as part of the ENSLIC project

| Building | Climate zone, Location | Typology | Type | Scale | Stage |
|----------|---|----------------------|------------|-----------------------------------|-------------------|
| CIR CS1 | South Europe - Zaragoza, Spain | Apartment block | Existing | 5 floors - 7641 m ² | In use |
| CIR CS2 | South Europe - Zaragoza, Spain | Apartment block | Existing | 7 floors - 8607 m ² | In use |
| CIR CS3 | South Europe - Zaragoza, Spain | Offices | Renovation | 2 floors - 1700 m ² | - |
| ARM CS1 | South Europe - Formerie, France | Semi-detached houses | Existing | 2 floors - 132 m ² | In use |
| ARM CS2 | South Europe - Montreuil, France | Apartment block | Existing | 6 floors - 5124 m ² | In use |
| ARM CS3 | South Europe - France | Apartment block | Design | 6 floors - 6600 m ² | Design phase |
| IFZ CS1 | Central Europe - Weiz, Austria | Semi-detached houses | Existing | 2 floors - 113,7 m ² | In use |
| IFZ CS2 | Central Europe - Weiz, Austria | Offices | Existing | 4 floors - 3068 m ² | In use |
| IFZ CS3 | Central Europe - Gutenberg, Austria | Semi-detached houses | Existing | 3 floors - 202,4 m ² | In use |
| EMI CS1 | Central Europe - Budapest, Hungary | Apartment block | Existing | 11 floors - 25138 m ² | In use |
| KTH CS1; | North Europe - Gävle, Sweden | Offices | Design | 4 floors - 3314 m ² | Design phase |
| KTH CS2; | North Europe - Sollentuna, Sweden | Offices | Design | 4_6 floors - 10000 m ² | Design phase |
| CAL CS1 | Central Europe - Frankfurt a. M., Germany | Apartment block | Existing | 9 floors - 2353 m ² | In use |
| CAL CS2 | Central Europe - Frankfurt a. M., Germany | Apartment block | Existing | 3 floors - 2662 m ² | In use |
| CAL CS3 | Central Europe - Frankfurt a. M., Germany | Apartment block | Existing | 4 floors - 1482 m ² | In use |
| ECO CS1 | Central Europe - Kollum, Netherlands | Detached house | Existing | 3 floors - 170 m ² | In use |
| ECO CS2 | Central Europe - Nieuwegein, Netherlands | Offices | Design | 92 floors - 16278 m ² | Design, tendering |

⁵⁶ <https://ec.europa.eu/energy/intelligent/projects/en/projects/enslic-building>

3.6.2. 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. The performance improvements assessed were:

- environmental impact as a result of material choices;
- reduction of carbon emissions from a 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 its own methodology, more specifically a simplified excel-sheet, based on ISO 14040-14043. The full list of proposed simplifications⁵⁷ are the following:

- 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 complexity⁵⁷:

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

3.6.3. 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 CO₂eq]
- Primary Energy Consumption [GJ]

Supporting indicator:

⁵⁷ Malmqvist T., Glaumann M., Scarperlini 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

- Energy demand for heating, cooling, lighting or other uses [kWh/m².year]

However, the life cycle stages, boundary conditions and functional units vary considerably, depending on the country or practitioner. In the case of the functional unit, a default lifespan of 50 years is assumed, 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, in the case of CIR CS3 distribution of GWP is as follows: 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 production stage) and to heating, cooling, domestic hot water and auxiliary energy consumption (in 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 a 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.

3.6.4. 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 the 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.

3.7. SKANSKA PLC

3.7.1. 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 projects⁵⁸ and interviews with representatives from individual Business Units (BUs) in each country. The cluster of buildings analysed is presented in Table 12.

⁵⁸Skanska (2012) Aspects of sustainability – case studies [online], available at <http://www.skanska-sustainability-case-studies.com/> [20/5/2016]

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 ⁵⁹. Skanska conducted 113 carbon footprints in 2015 to benchmark project carbon emissions and to help identifying low-carbon project options, which can result in project carbon and financial savings.

Table 12: 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 ² | In-use |
| Cold Harbour Lane | Central Europe, London (UK) | Residential: apartment block | New-build | 2 buildings, 6 to 9 stories, 9.747 m ² per building, 108 apartments | In-use |
| Sollallén townhouses | Northern-Europe, Växjö (SE) | Residential: terraced, semi-detached | New-build | 21 dwellings (ranging from 79 m ² to 91 m ²) | In-use |
| Väla Gård | Northern Europe, Helsingborg (DK) | Office, medium rise | New-build | 1.777 m ² | In-use |
| Bassängkajen | Northern Europe, Malmö (SE) | Office, medium-rise | New-build | 8.500 m ² (phase 1) 7.800 m ² (phase 2) | In-use |
| Powerhouse Kjørbo | Northern Europe, Sandvika (NO) | Office, low- and medium-rise | Renovation | 5.180 m ² (total); 2 buildings | In-use |
| Atrium 1 | Central Europe, Warsaw (PL) | Office, high-rise | New-build | 15 stories, 16.300 m ² (office space) | In-use |
| Corso Court | Central Europe, Prague (CZ) | Office, medium-rise | New-build | 7 stories, 17.202 m ² (office space) | In-use |
| Riverview | Central Europe, Prague (CZ) | Office, medium-rise | New-build | 7 stories, 7.037 m ² (office space) | In-use |
| City Green Court | Central Europe, Prague (CZ) | Office | New-build | 8 stories, 16.300 m ² (office space) | In-use |
| Open Garden | Central Europe, Brno (CZ) | Office | New-build, renovation | 1.454 m ² (re-furbished); 2.900 m ² (new-build) | In-use |
| Green House | Central Europe, Budapest (HU) | Office medium-rise | New-build | 8 stories, 17.900 m ² (office space) | In-use |

3.7.2. 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 ⁶⁰. In this field study analysis, the main focus is on carbon, one of the four key components of the Color Palette.

⁵⁹ Skanska (2015) *Carbon* [online], available at: <http://group.skanska.com/sustainability/environmental-responsibility/carbon/> [20/5/2016]

⁶⁰ 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]

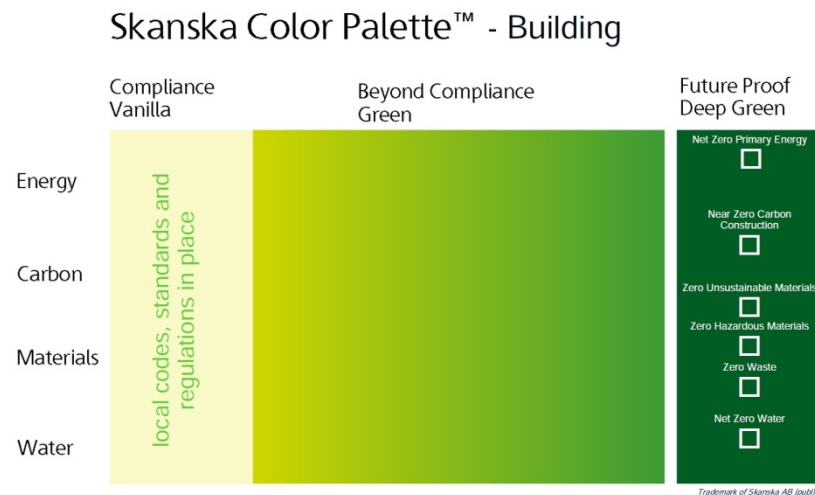


Figure 11: Skanska color palette

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% CO₂-reduction;
3. 50% CO₂ 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 available⁶¹. For instance:

- Skanska Norway uses the Norwegian government's carbon calculation tool (Klimagassregnskap⁶², (v1 was launched in 2007, current version is v5));
- Skanska Finland trialed the use of BIM (Building Information Modeling);
- The Swedish BU uses the ECO₂-tool, which is based on the LCA/LCC tool Anavitor, developed by the Swedish Environmental Research Institute (IVL)⁶³.

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.

⁶¹ 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]

⁶² Klimagassregnskap (2016) *Klimagassregnskap*, Available at <http://www.klimagassregnskap.no/> [20/5/2016]

⁶³ Anavitor (2016) *Anavitor* [online], available at <http://www.anavitor.se/> [20/5/2016]

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 impact⁶⁴. 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.

3.7.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

Key indicators identified regarding carbon emissions are:

- Embodied carbon [tCO_2eq or normalized $\text{kgCO}_2\text{eq}/\text{m}^2$]
- Operational carbon [$\text{kgCO}_2\text{eq}/\text{m}^2/\text{yr}$]
- Carbon footprint [tCO_2eq or normalized $\text{kgCO}_2\text{eq}/\text{m}^2$]

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 lifespan 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).

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 (klimagassregnskap.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 estimates, Bill of Quantities, BIM, discussions with designers and contractors, and literature. For as-

⁶⁴ Van de Vyver I. and Larsson G. (2016). *Use of carbon footprint in Skanska SE*

built documentation, BIM-models are usually the most reliable source [interview with SKANSKA NO⁶⁵].

3.7.4. 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% CO₂-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. 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 Republic⁶⁶].

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.

3.8. GREEN BUILDING COUNCIL FINLAND, BUILDING PERFORMANCE INDICATOR PILOTS

3.8.1. 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 database contains 20 to 25 buildings (with the majority office buildings). The selected building are listed in Table 13.

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 13: Buildings that have reported performance using the GBCF Building Performance Indicators

| Building | Climate zone, Location | Typology | Type | Scale | Stage |
|-----------------------------|--------------------------|----------|-----------|---|----------------------|
| The Ministry of Environment | Northern-Europe, Finland | Office | Renovated | 8.436 m ² (GFA ⁶⁷) | design 2013/use 2015 |

⁶⁵ Van de Vyver, I. and Fjeldheim, H. (2016). *Interview with Skanska NOR regarding carbon footprint*

⁶⁶ Van de Vyver, I. and Lhoták, P. (2016). *Interview with Skanska CZ regarding carbon footprint*

⁶⁷ GFA: Gross Surface Area

| | | | | | |
|------------------------------|--------------------------|--------|-----------|---|-------------|
| Peab, Ultimate Business Park | Northern-Europe, Finland | Office | New-build | 12.490 m ² (GFA) / 550 persons | design 2014 |
| Wood City, SRV | Northern-Europe, Finland | Office | New-build | 12.800 m ² (GFA) | Design 2015 |
| The Ministry of Environment | Northern-Europe, Finland | Office | New-build | 58.296 m ² (GFA) | In-use 2013 |
| Nokia-House 4 | Northern-Europe, Finland | Office | New-build | 6.407 m ² (GFA) | In-use 2013 |
| Quartetto | Northern-Europe, Finland | Office | New-build | 8.040 m ² (GFA) | In-use 2013 |
| Säterinkatu | Northern-Europe, Finland | Office | New-build | 30.270 m ² (GFA) | In-use 2013 |
| Pöyrytalo | Northern-Europe, Finland | Office | New-build | 8.735 m ² (GFA) | In-use 2013 |
| Kathy / Skanska | Northern-Europe, Finland | Office | New-build | 58.296 m ² (GFA) | In-use 2013 |

3.8.2. 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 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.

3.8.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

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

- E-Value Indicator [kWh/m²year]
- Life-Cycle Carbon Footprint Indicator [kg CO₂eq/netto-m²/evaluating period]
- Operational Carbon Footprint Indicator [kg CO₂eq/heated m²]
- Measured Energy Consumption Indicator [kWh/heated brm²]
- 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.

The Operational Carbon Footprint Indicator is calculated according to the Green House Gas (GHG) Protocol. The Measured Energy Consumption Indicator measures the consumption of purchased energy in a property. The 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.

3.8.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

In general, the guides for conducting calculations for the various indicators are very well-written and available online. The calculation tools available on the 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 customers who are willing to pay for the calculation of these indicators.

A summary of practical experience of calculating selected indicators is provided in the subsequent paragraphs⁶⁸.

The E-value is mandatory according to the 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 the E-value indicator is not comparable with the measured energy consumption indicator, due to the weighted coefficients of different energy sources. 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 (online tool). This is straightforward once the required data is available. The most time-consuming part is to get the needed data in a proper and usable format.

The 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.

3.9. IRCOW

3.9.1. 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 Tecnia (coordinator) and VITO.

⁶⁸ 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*

IRCOW developed and validated upgraded technological solutions to achieve an efficient material recovery from (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 14: IRCOW FP7 project in-field case studies

| Building | Climate zone, Location | Typology | Type | Scale (m ²) | 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 |

3.9.2. 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 work. 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.

3.9.3. 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).

3.9.4. 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 work, 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 work 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 aggregates⁶⁹).

3.10. OFFICAIR

3.10.1. BACKGROUND AND CONTEXT TO SELECTION OF THE CLUSTER

Officair⁷⁰ 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 15: 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 |

⁶⁹ Xia H., Bakker M.C.M., 2014. *Reliable classification of moving waste materials with LIBS in concrete recycling*. Talanta (120), 239-247.

⁷⁰ Officair (2013) *Officair* [online] <http://www.officair-project.eu/> [20/5/2016]

| | | | | | |
|--------------------|----------------|---|--|---|--------|
| 5 Office buildings | Eastern Europe | Offices: low-rise, medium-rise, high-rise | offices' New-build and renovated, all existing ('modern offices' | Up to 5 stories; 4 units in each building | In use |
|--------------------|----------------|---|--|---|--------|

3.10.2. 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.

The measurement methods applied are illustrated in the case of Greece (Sakellaris et al., 2013)⁷¹:

"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, O₃ and NO₂.

Additionally, PM_{2.5} 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).

3.10.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

Key indicators:

- VOCs, TVOC, aldehydes [$\mu\text{g}/\text{m}^3$]
- particulate matter (PM_{2.5}, PM₁₀) [$\mu\text{g}/\text{m}^3$]
- O₃ [$\mu\text{g}/\text{m}^3$]
- NO₂ [$\mu\text{g}/\text{m}^3$]
- Indoor/outdoor (I/O) ratios of pollutants
- Flow rate [l/s/per; l/s/m²; m³/h]
- Air Change rate per hour (ACH) [h⁻¹]

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_{2.5}*.

⁷¹ I.A. Sakellaris, D.E. Saraga, K.K. Kalimeri, E.M. Kouglioumtzidis, V.G. Mihucz, R. Mabilia and J.G. Bartzis (2013) *Air Quality measurements in indoor environment of modern offices in Athens, Greece (Officair Project)*

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, α -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 O₃ and NO₂ indicate the contrary).

3.10.4. 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 EnVIE⁷² 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 as 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, e.g. 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.

⁷² EnVIE (2009) *Objectives and approach of EnVIE* [online], available at: <http://paginas.fe.up.pt/~envie/> [20/5/2016]

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 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.

3.11. CLEAN AIR, LOW ENERGY

3.11.1. 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 schools⁷³. 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 built with a lightweight timber frame structure, the others have a more common brick or concrete structure.

3.11.2. 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 were collected using diffusive passive samplers to monitor TVOC, VOC and aldehydes; air samplers to monitor particulate matter; measurement units to record CO₂, 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.

⁷³ Clean Air, Low Energy (2012), <https://esites.vito.be/sites/cleanairlowenergy/EN/home/Pages/home.aspx>

3.11.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

Key indicators:

- Indoor air pollutant concentrations (VOCs, TVOCs, aldehydes, particulate matter $PM_{2.5}$, $PM_{10.0}$) [$\mu g/m^3$]
- Flow rate [m^3/h]
- Air Change Rate or Air Changes per Hour (ACH) [$m^3/m^3/hr$ @50Pa]
- Airtightness n50 [$m^3/m^3/hr$ @50Pa]
- Concentration of biological agents (fungi, yeast and total bacteria) [Colony Forming Units (CFU)/ m^3]

Supporting indicators:

- Temperature [K]
- Relative Humidity (RH) [%]
- Indoor CO_2 concentration [ppm]

Regarding hazardous substances, of all identified VOCs in Clean Air Low Energy, formaldehyde, d-limonene, α -pinene, and toluene were most abundant in indoor air. Regarding biological agents, the average levels of total viable fungi indoors were comparable or slightly lower compared to the outdoor average concentrations (1.5×10^2 and 4.2×10^2 CFU/ m^3 , respectively).

Regarding flow rate and air change rates, the measurement results as illustrated in Figure 2 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 standard⁷⁴ (about 1 ACH).

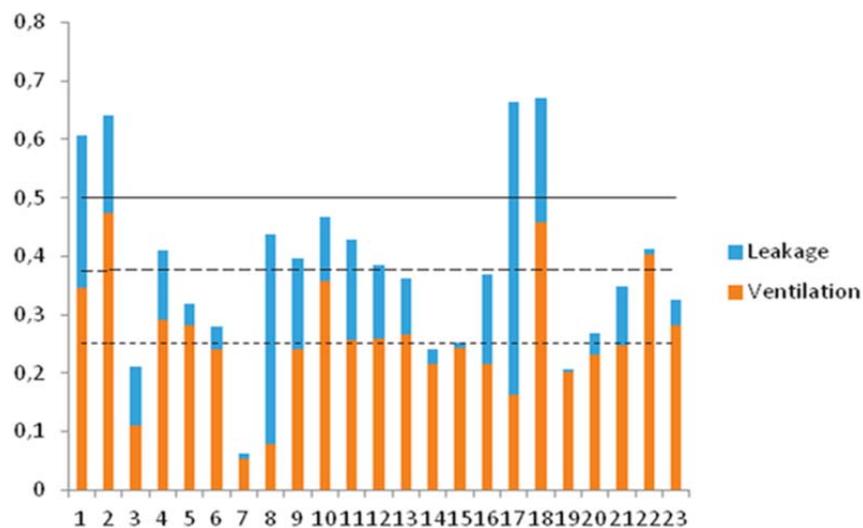


Figure 12: Total air change rate (ACH) in the residences, subdivided by leakage and ventilation

⁷⁴ BIN, Ventilatievoorzieningen in woongebouwen, in, Brussels, 1991

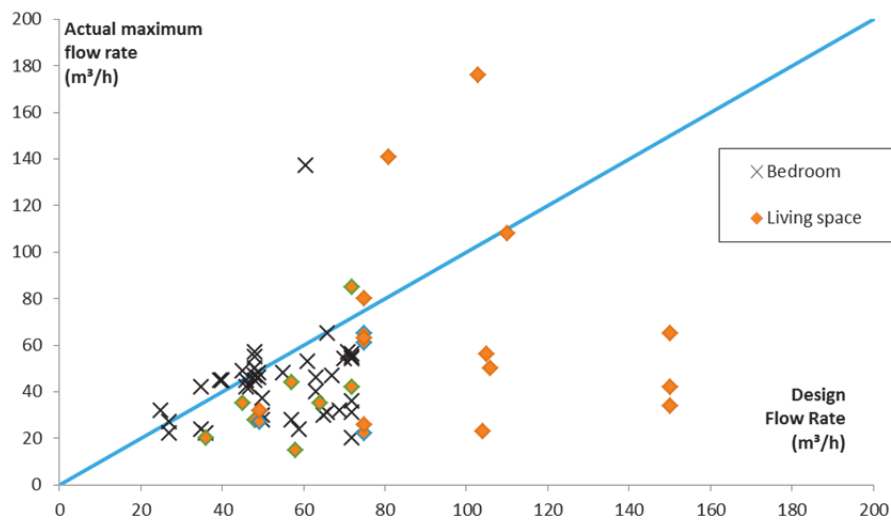


Figure 13: Actual maximum mechanical flow rate and design flow rate for all living spaces and bedrooms in the residences with heat recovery ventilation

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:

- 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 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 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 four 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.

3.11.4. 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 the 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.

3.12. RENOVAIR

3.12.1. 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 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 16: 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 |

3.12.2. 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 airtightness 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 wanted to achieve a healthy IAQ by choosing low-emission building materials. Besides the applicable EU regulations, Belgium has limited regulations that restrict building material emissions, and has no mandatory product label for building products available on the Belgian market.

3.12.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

Key indicators identified:

- indoor/outdoor ratios of indoor air pollutants (I/O-ratio): PM_{2.5}, CO₂, 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.

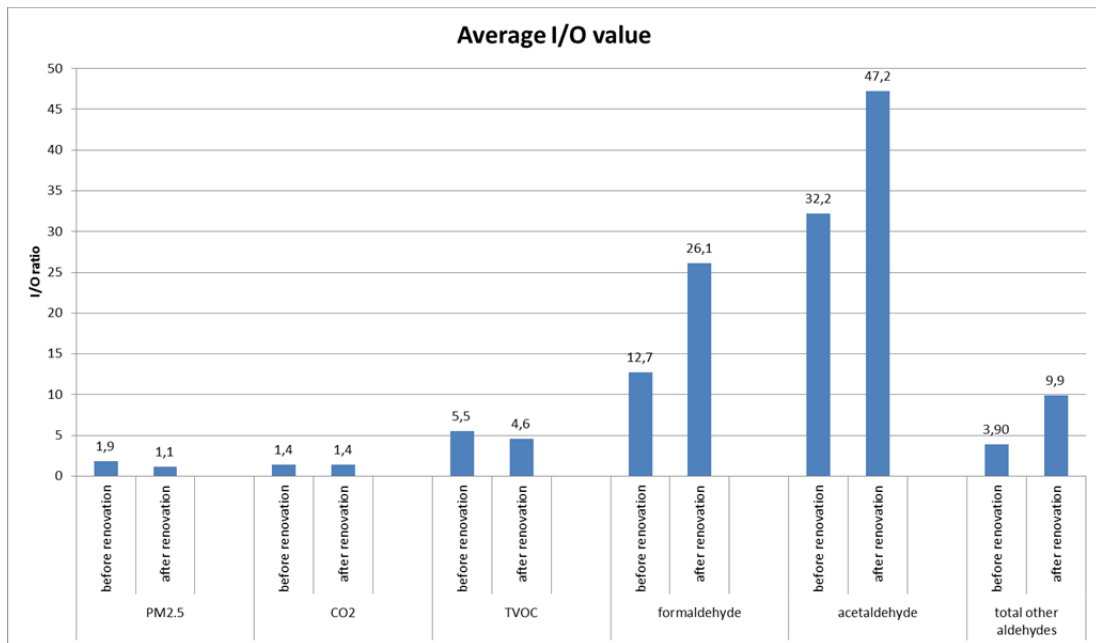


Figure 14: Indoor/Outdoor ratios (I/O-ratio) prior to and 6 months after the renovations for selected hazardous substances (source: Renovair)

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_{2.5} 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 CO₂ 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/m³). Six months after the renovation the concentration levels had decreased to levels classified by the same institution as 'ideal conditions'.

In only one of the two case studies, 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 work) also affected the airtightness of the building.

3.12.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

According to the Renovair data, thermal bridges present before the renovation were in some cases found to be more pronounced post renovation. The airtightness 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 context⁷⁵.

3.13. INSULAtE

3.13.1. BACKGROUND AND CONTEXT TO SELECTION OF THE CLUSTER

INSULAtE is a European project, co-financed by EU Life+ programme (project Life number: LIFE09 ENV/FI/000573)⁷⁶. Project coordinator is THL (The National Institute for Health and Welfare), other project partners are the Tampere University of Technology-Dept. of Civil Engineering (Finland), the Kaunas University of Technology-Dept. of Environmental Engineering, (Lithuania) and the World Health Organization-European Centre for Environment and Health (Bonn Office, Germany)

Table 17: INSULAtE field study locations and buildings

| Building | Climate zone, Location | Typology | Type | Scale | Stage |
|------------------------|------------------------|---------------------------------|------------|----------------------------------|---|
| 46 apartment buildings | Northern Europe | residential: multi-family house | renovation | 241 flats (5 flats per building) | In use Fieldwork before and after renovation in 39 |

⁷⁵ 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]

⁷⁶ http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3725

| | | | | | | | apartment buildings |
|----|---------------------|----------------|---------------------------------|------------|---------------------------------|--|--|
| 20 | apartment buildings | Eastern Europe | residential: multi-family house | renovation | 96 flats (5 flats per building) | | In use before and after renovation in 15 apartment buildings |

3.13.2. TRANSLATION OF THE MACRO-OBJECTIVE INTO ACTIONS AND IMPROVEMENTS BY BUILDINGS IN THE CLUSTER

The research objectives, methodologies applied and indicators assessed in INSULAtE are similar to the ones covered in Renovair, but while Renovair focusses on the relation of energy efficient renovations in the Belgian (Central-European) context, INSULAtE focusses on this relation in the Scandinavian (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.

INSULAtE addresses macro-objective B4 “Healthy and comfortable spaces” and in particular the exposure of hazardous substances as a result of ventilation intake air and material emissions. Moisture and mould is considered as well, but to a lesser extent.

Assessments were performed in a total of 46 Finnish and 20 Lithuanian apartment buildings (about five 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. 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 questionnaire was based on a formerly developed Housing and Health questionnaire, which has been used to collect comparative data from random samples of Finnish dwellings in 2007 and 2011 [1, 2]. 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).

The assessment protocol is explained in detail in the project website⁷⁷.

3.13.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

Assessment included the following measurements of indoor environmental quality indicators that may impact the health and wellbeing of residents⁷⁸:

- Indoor temperature (T) and relative humidity (RH)
- Air change rate (ACR)
- Carbon dioxide (CO₂) and carbon monoxide (CO)
- Particulate matter (PM_{2.5}, PM₁₀)
- Nitrogen dioxide (NO₂)
- Volatile organic compounds (VOC)

⁷⁷ INSULAtE (2016) *INSULAtE* [online], available at: www.insulateproject.eu [20/5/2016]

⁷⁸ 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

- Formaldehyde (CH₂O)
- Radon
- Microbes and fibres in settled dust.

3.13.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

A selection of key findings that emerged in the study are the following:

- A majority of the apartments fulfilled the national guideline values for IEQ parameters, but after the retrofits some indoor pollution sources emerged. This indicates that special attention should be said to pollution source control
- Finnish buildings exceeded the maximum recommended indoor temperature during heating seasons (23 °C) for about 40% of the time both before and after retrofits, while relative humidity was often below recommended (RH <20%). Lowering high indoor temperatures could help to save energy and maintain more acceptable RH

3.14. IDOM AND NEW4OLD (SPAIN)

3.14.1. 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 strategy 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 18: 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 ² | In use |
| IDOM Bilbao Headquarters | Southern-Europe, Bilbao, Spain | Office: medium-rise | New-build | 5 stories, 14400 m ² | In use |
| Rental social housing building | Southern-Europe, Zaragoza, Spain | Residential: apartment block | Renovation | 4 stories | In use |



Figure 15: IDOM Madrid headquarters (left) and IDOM Bilbao headquarters (right)

3.14.2. 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 with a 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 with the IHACRES software (e.g. IHACRES⁷⁹) have been used for the simulations 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 a free-running building.

The 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. For 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;

⁷⁹ Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data (IHACRES), <http://www.toolkit.net.au/tools/IHACRES>

- Prototype of passive solar heating.

3.14.3. 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.

3.14.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

In Spain the external temperatures considered for the design of office buildings are usually slightly higher than the current temperatures. This is done, to take into account a probable temperature rise in the next few years during the lifespan of a building.

Moreover, 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 the UKCP 2003 Methodology to identify potential climate change risks, e.g. sea level increase and precipitation increase. For this goal, a hydrometeorology model is built and simulated by using IHACRES software.

IDOM has started to use parametric simulations. 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.

3.15. DESIGN FOR FUTURE CLIMATE (D4FC)

3.15.1. 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 19: 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 ² | In-use |
| 100 City Road, ARUP | Central Europe, London (UK) | Office, high-rise | New-build | 16000 m ² | In-use |
| Admiral HQ, Glen Howell | Central Europe, Cardiff (UK) | Office, medium-rise | New-build | 18580 m ² | In-use |



Figure 16: Co-operative HQ (left), 100 City Road (Middle), Admiral HQ (Right)

3.15.2. 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 Network⁸⁰:

- 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)⁸¹. UKCP09 provides future climate projections for land and marine regions as well as observed (past)

⁸⁰ MBE, KTN, Guidance for making the case for climate change adaptation in the built environment, 2013

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.

3.15.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The main indicators identified in this field study are as the following:

- 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. An example is given in Figure 17 and Figure 18. A comparison is made between the operative temperatures under different climate profiles (2005 and 2050s).

⁸¹ <http://ukclimateprojections.metoffice.gov.uk/21678>

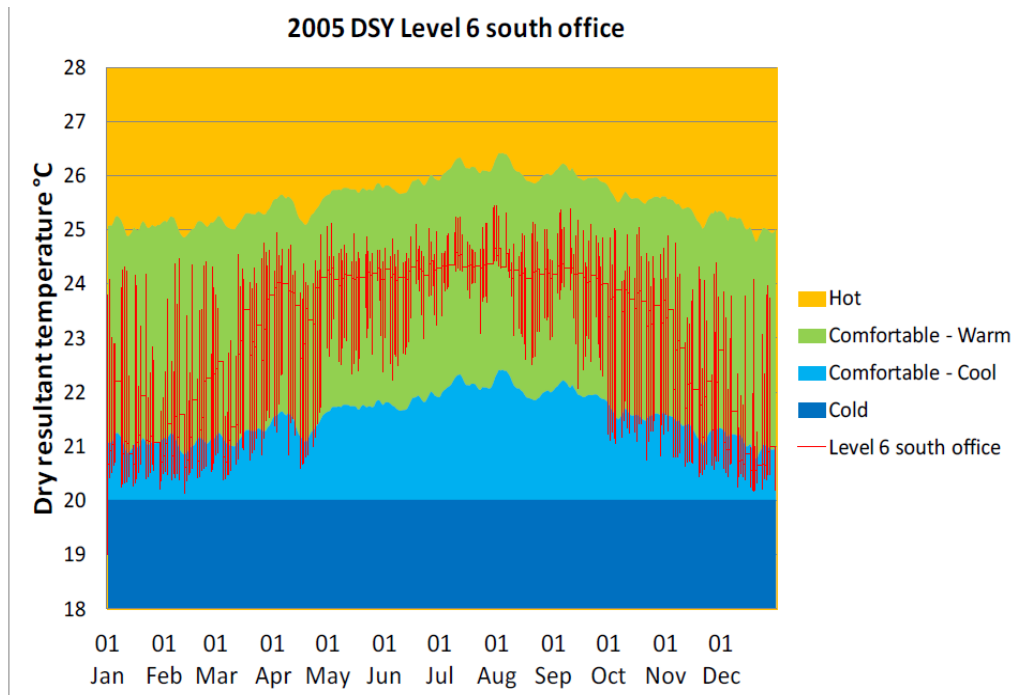


Figure 17: Indicative simulation results for the Co-operative Head Office (Manchester) based on 2005 data

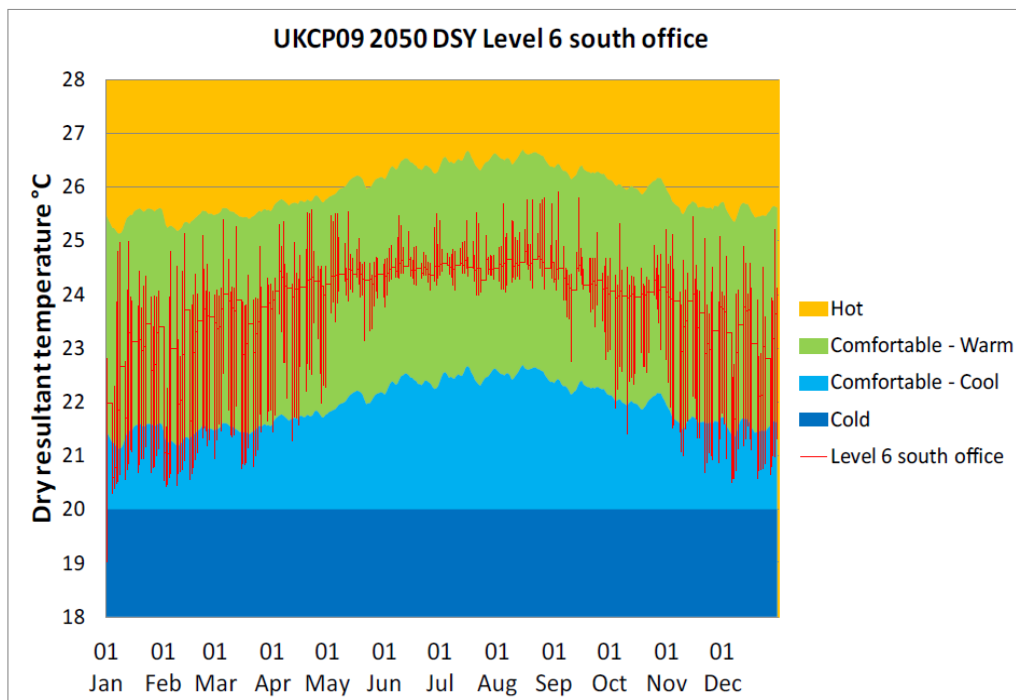


Figure 18: Indicative simulation results for the Co-operative Head Office (Manchester) for the 2050s scenario

Source: Ren et al (2012)⁸²

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.

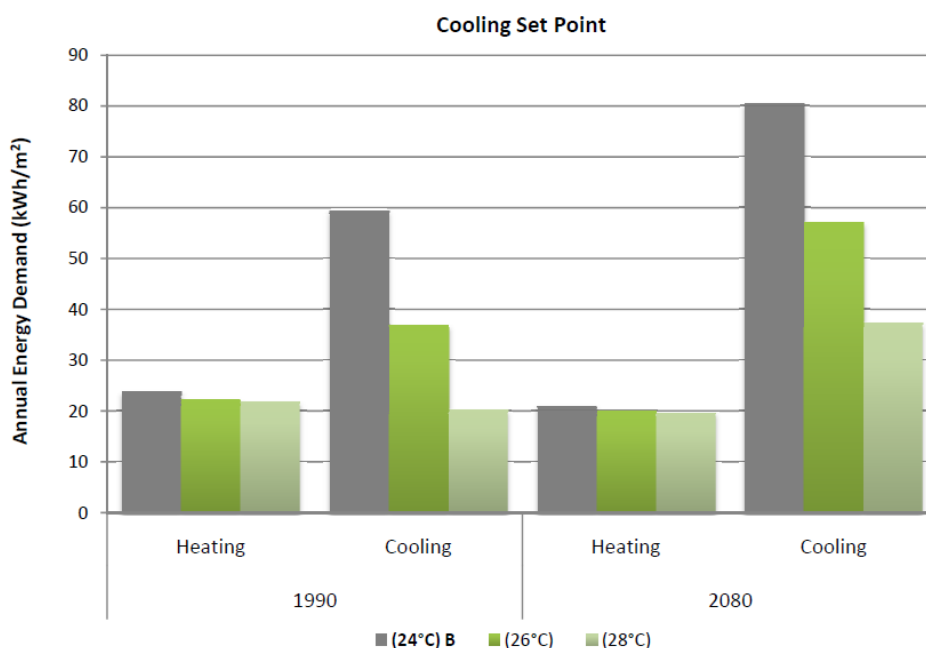


Figure 19: Indicative simulations of the additional heating and cooling energy demand for the 1990s and 2080s climate profiles for Admiral HQ, UK

Source: Beddoe, N (2012)⁸³

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.

⁸² Ren, M., Shankland, N and Brayshaw, V (2012). *The Co-operative Head Office Climate Change Adaptation Study Final Report*.

⁸³ Beddoe, N. (2012). *Design for Future Climate – Developing an Adaptation Strategy Admiral Headquarters Cardiff*.

3.15.4. 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. In the UK solid research has been conducted on future climate predictions. 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 studies might not be possible due to lacking future climate data. 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 focussed on building 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.

3.16. KNOWLEDGE FOR CLIMATE (K4C)

3.16.1. 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 20: 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 |

3.16.2. 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.

3.16.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The indicators in this field study are identified as:

- Temperature [°C]
- Overheating hours [h]
- Overheating 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 20* 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. Overheating 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.

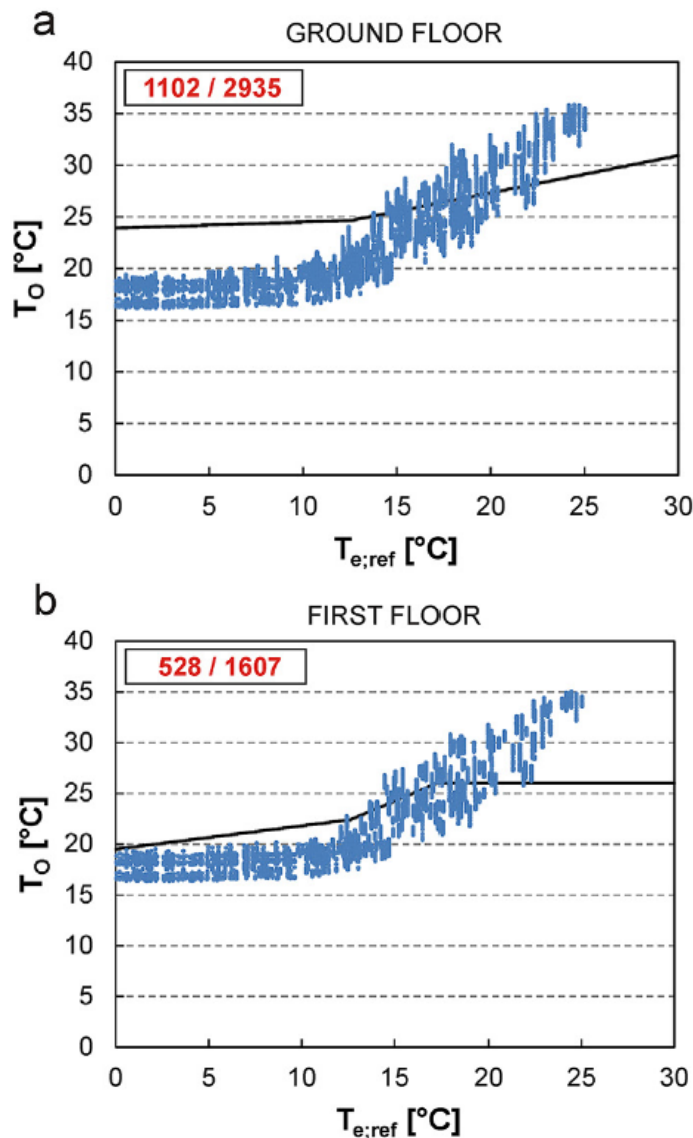


Figure 20: Example temperature variances for the detached house by floor

Source: Van Hooff et al (2015)⁸⁴

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.

⁸⁴ 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*

3.16.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

The dynamic simulation were 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 an 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 future 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. One potential concern is that dynamic simulation can be time intensive/costly and expertise-demanding. Therefore, it makes sense to conduct dynamic simulation for large scale projects, but may not be practical for every single building project, especially not for residential buildings.

3.17. DAVIS LANDON CASE STUDIES

3.17.1. BACKGROUND AND CONTEXT TO SELECTION OF THE CLUSTER

In 2006 the European Commission appointed Davis Langdon from the UK to undertake a project to develop a common European methodology for Life Cycle Costing (LCC) in construction. The thematic strategy on 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 their life cycle costing. It was felt that the construction sector and its clients (and, in particular, public procuring authorities) could help improve the sector's environmental performance and realise potential cost savings by concentrating on the early integration of environmental considerations in the construction cycle.

It was recommended to develop and adopt a common European methodology for LCC in construction taking into account the work done under international standard ISO 15686. The scope of this study was therefore identified as providing an analysis and evaluation of the different national approaches for LCC, as well as elaborating an approach for the estimation of Life Cycle Costs and related indicators for buildings and constructed assets which could be of added value at EU level.

Table 21: Selection of relevant cases covered by the Davis Langdon study

| Building | | Climate zone, Location | Typology | Type | Scale | Stage |
|--------------|----------|--------------------------|------------------|------------|-----------------------------|--------|
| Kuopio House | Taxation | Northern-Europe, Finland | Office: low-rise | Renovation | - | In-Use |
| Meaux | Shopping | Central-Europe, | Retail | New-build | GUA 70.000 m ² . | Design |

| | | | | | | |
|----------------------------------|-----------------------------|-------------------------|--|------------|--|--------|
| Centre | France | | | | 42.000 m ² of green/entertainment space | |
| Kempkensberg Project | Central-Europe, Netherlands | Office: high-rise | New-build | | GA 46.850 m ² . 12.000 m ² garden | Design |
| Rikshospitalet | Northern-Europe, Norway | Health, hospital | New-build | | GA 100.000 m ² subdivided in different functional areas | Design |
| New House | Opera | Northern-Europe, Norway | Culture | New-build | GA 40.000 m ² subdivided in two parts audience and production. | Design |
| Uppsala Entrance | Northern-Europe, Sweden | Residential | New-build | | 7 buildings, 90 apartments | Design |
| Southampton City College | Central-Europe, UK | Education | Combination of refurbishment and new build | | New build: hub building 3-storey block, block 2 3-storey teaching building and service single-storey building Refurbishment: block B theatre and block E 3-storey | Design |
| Wandsworth Bridge Primary Centre | Road Care | Central-Europe, UK | Health | Renovation | - | In-Use |
| Steletova 8 Social Housing | Southern-Europe, Slovenia | Residential | Renovation | | 3.800 m ² net floor area, 60 apartments | In-Use |

The selected case studies refer only to the buildings, not the infrastructure ones, such as the motorway in the Netherlands. The focus is on residential and offices however the methodology employed for the cultural and health buildings was also looked into in this collection of information.

3.17.2. TRANSLATION OF THE MACRO-OBJECTIVE INTO ACTIONS AND IMPROVEMENTS BY BUILDINGS IN THE CLUSTER

The EU LCC Methodology is the common methodology developed within the project. The methodology can be summarized in 15 steps represented in Figure 21.

| STEP | OUTCOME / ACHIEVEMENT | | |
|--|--|--|--|
| 1 Identify the main purpose of the LCC analysis | Statement of purpose of analysis Understanding of appropriate application of LCC and related outcomes | 9 Verify values of financial parameters and period of analysis | Period of analysis confirmed Appropriate values for the financial parameters confirmed Taxation issues considered Application of financial parameters within the cost breakdown structure decided |
| 2 Identify the initial scope of the analysis | Understanding of: Scale of application of the LCC exercise Stages over which it will be applied Issues and information likely to be relevant Specific client reporting requirements | 10 Review risk strategy and carry out preliminary uncertainty/ risk analysis | Schedule of identified risks verified Qualitative risk analysis undertaken – risk register updated Scope and extent of quantitative risk assessment confirmed |
| 3 Identify the extent to which sustainability analysis relates to LCC | Understanding of: Relationship between sustainability assessment and LCC Extent to which the outputs from a sustainability assessment will form inputs into the LCC process Extent to which the outputs of the LCC exercise will feed into a sustainability assessment | 11 Perform required economic evaluation | LCC analysis performed Results recorded for use at Step 14 |
| 4 Identify the period of analysis and the methods of economic evaluation | Identification of the period of analysis and what governs its choice Identification of appropriate techniques for assessing investment options | 12 Carry out detailed risk/uncertainty analysis (if required) | Quantitative risk assessments undertaken Results interpreted |
| 5 Identify the need for additional analyses (risk/uncertainty and sensitivity analyses) | Completion of preliminary assessment of risks/ uncertainties Assessment of whether a formal risk management plan and/or register is required Decision on which risk assessment procedures should be applied | 13 Carry out sensitivity analyses (if required) | Sensitivity analyses undertaken Results interpreted |
| 6 Identify project and asset requirements - | Definition of the scope of the project and the key features of the asset Statement of project constraints Definitions of relevant performance and quality requirements Confirmation of project budget and timescales Incorporation of LCC timing into overall project plan | 14 Interpret and present initial results in required format | Initial results reviewed and interpreted Results presented using appropriate formats Need for further iterations of LCC exercise identified |
| 7 Identify options to be included in the LCC exercise and cost items to be considered | Identification of those elements of an asset that are to be subject to LCC analysis Selection of one or more options for each element to be analysed Identified which cost items are to be included | 15 Present final results in required format and prepare a final report | Final report issued, to agreed scope and format Complete set of records prepared to ISO 15686 Part 3 |
| 8 Assemble cost and time (asset performance and other) data to be used in the LCC analysis | Identification of: All costs relevant to the LCC exercise Values of each cost Any on-costs to be applied Time related data (e.g. service life/maintenance data) | | |

Figure 21: Summary of the fifteen steps of the methodology. Steps 10, 12 and 13 are not compulsory.

The common methodology for Life Cycle Costing was applied in a number of cases across Europe with different objectives (see Table 22). A simplified methodology was applied in two cases: Kuopio Taxation House in Finland and the Meaux Shopping Centre in France.

Table 22: Overview of the different applications of Life Cycle Costing in the Davis Langdon case studies

| Case study | Objective |
|-------------------------------------|--|
| Kuopio Taxation House, Finland | Two energy saving solutions investigated. Assessment of the best HVAC option |
| Meaux Shopping Centre, France | Inform the choice of materials during design process. No results available at the time of finalizing the report. |
| Kempkensberg Project, Netherlands | Used for procurement, environmental and assessment of future costs purposes. |
| Rikshospitalet, Norway | Retrospectively to compare actual operational costs in relation to the original LCC assessment |
| New Opera House, Norway | The goal was to produce costs estimates of likely Maintenance Operation and Management costs over 60 and 150 years taking into account the design choices made |
| Uppsala Entrance, Sweden | To assess the financial implications of systems and components. |
| Southampton City College, UK | Outline business case and become a key component in the design and construction decisions |
| Wandsworth Bridge Road Primary Care | To inform a new build or refurbish strategic decision. |

| | |
|--------------------------------------|--|
| Centre, UK | |
| Steletova 8 Social Housing, Slovenia | Post competition evaluation to assess the energy efficiency solutions used for a low carbon refurbishment project. |

3.17.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The key indicators identified were:

- Total Net Present Cost⁸⁵ [local currency or local currency per m²]

3.17.4. IMPLEMENTATION EXPERIENCE OF PRACTITIONERS INVOLVED WITH DELIVERY OF THE IMPROVEMENTS

The general feedback is that the methodology was very useful for the case studies and its steps fitted well within existing LCC practices in the countries analysed. No instances were found where the methodology could not be applied because of its unsuitability. The instances where the methodology could not be applied precisely were mainly in countries where LCC use is not sufficiently matured.

The methodology could be applied to all different types and sizes of projects. For smaller project or for projects where LCC is applied purely for systems or component evaluation, the methodology can be applied in a simplified way to reflect the lower level of complexity of the issue investigated.

The application of the methodology suggests that during the 'in use' phase, there appears to be a certain 'optimistic' approach in the way LCC is applied at initial stages of projects that leads to inaccurate assumptions for maintenance and operational costs. This is primarily due to lack of real data from operational assets to input into the LCC calculations but also relates to the way buildings or systems are used in real life. Initially, the application of the methodology at this stage was originally considered 'too mature' in relation to the level of use for LCC across Europe and it wasn't a key target.

3.18. LCC-DATA

3.18.1. 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.

⁸⁵ 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.

Table 23: 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 ² . 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 ² 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 ² per floor. 30.000 m ² 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 ² and other with 4.749 m ² 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 ² net floor area, 60 flats | In-Use |
| TECHbase | Central-Europe, Austria | Office: low-rise | Renovation | Rentable floor area of 12.500 m ² of which 7.500 m ² is used as office area | In-Use |
| BRC | Central-Europe, Austria | Office: medium-rise | Renovation | 7 storeys. Rentable floor area 5.110 m ² | In-Use |
| Mariahilfer Strasse | Central-Europe, Austria | Office | Renovation | 7 storeys. Rentable floor area 3.600 m ² 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 ² net ground floor | In-Use |
| Culture_1 | Central-Europe, Germany | Offices and museum | Renovation | 15 properties. 79.165 m ² net ground floor | In-Use |
| School_1 | Central-Europe, Germany | Schools | Renovation | 9 properties. School and gym buildings. 92.692 m ² net ground floor | In-Use |

3.18.2. 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.

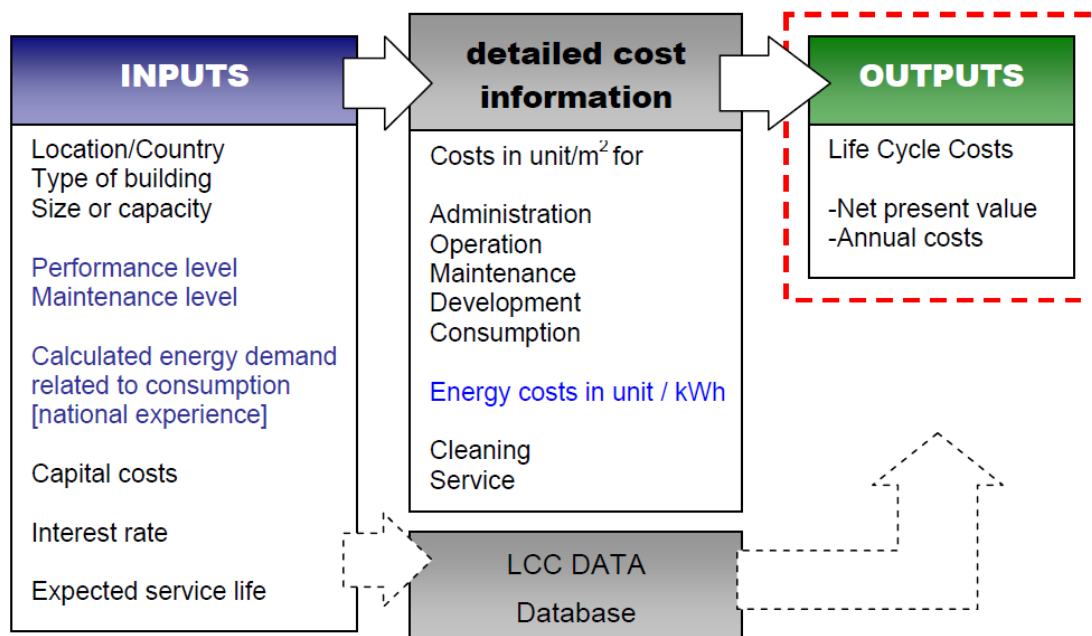


Figure 22: Overview of LCC-Data approach

Source: LCC-Data (2009)

The project concludes that for design decisions related to the building type and size, the developer may rely on level 1 analysis. 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.

3.18.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The key indicators identified were:

- Annual costs [local currency per year or normalized per m² per year]
- Total Net Present Cost⁸⁶ [local currency or local currency per m²]

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:

- 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 m² 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 CO₂ emissions (kgCO₂CO₂eq/m²/yr) and primary energy consumption (kWh/m²/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 CO₂ emissions and energy and water savings. This is illustrated by the Slovenian case study.

3.18.4. 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 lifespans assumed. Moreover, the goal of the project was to compare *within each case* the level 1 and level 2 calculations.

⁸⁶ 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.

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.

3.19. IMMO-VALUE

3.19.1. 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 project⁸⁷, 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.

⁸⁷ European Commission (2016) *IMMOVALUE* [online], available at:
<https://ec.europa.eu/energy/intelligent/projects/en/projects/immovalue> [20/5/2016]

Table 24: Schedule of projects analysed as part of IMMO-VALUE

| Building | Climate zone, Location | Typology | Type | Scale | Stage |
|---|--------------------------|----------------------------------|------------|--|--------|
| Modified Income approach | | | | | |
| Vienna Offices building | Central-Europe, Austria | Office: mid-rise | Renovation | GFA ⁸⁸ of approx. 30,000 m ² GLA of 21,421 m ² . | In-Use |
| Tenement in Graz | Central-Europe, Austria | Residential: apartment building | Renovation | GFA of approx. 3,000 m ² GLA of 2,000 m ² . | In-Use |
| Condominium in Bad Häring/Kufstein | Central-Europe, Austria | Residential / office | Renovation | GLA ⁸⁹ of 92.53 m ² . | In-Use |
| Condominium in Feldkirch–Toster | Central-Europe, Austria | Residential: apartment building | Renovation | GLA of 94.58 m ² . | In-Use |
| Commercial Unit in Vienna – Freehold Interest | Central-Europe, Austria | Residential: apartment building | Renovation | GLA of 59.78 m ² . | In-Use |
| Community Center in the Ruhr Area | Central-Europe, Germany | Mix residential / office | Renovation | GFA of approx. 12,908 m ² and GLA of 10,757 m ² . | In-Use |
| Multi-family Building in the Rhine-Main Area | Central-Europe, Germany | Residential: apartment building | Renovation | GFA of approx. 6,120 m ² and GLA of 4,095 m ² . | In-Use |
| Office Building in the Oresund-Region | Northern-Europe, Sweden | Office | Renovation | GFA of approx. 23,014 m ² and GLA of 16,440 m ² . | In-Use |
| Care Retirement Home in the Ruhr Area | Central-Europe, Germany | Residential | Renovation | GFA of approx. 5,750 m ² and GLA of 4,286 m ² . | In-Use |
| Modified Sales Comparison Approach | | | | | |
| Residential property in Iasi | Southern-Europe, Romania | Residential: apartment building | Renovation | GLA of 234.26 m ² . | In-Use |
| Modified Cost Approach | | | | | |
| Single-family House in St. Christophen | Central-Europe, Austria | Residential: single-family house | Renovation | GFA main building 230 m ² . | In-Use |
| Single-family House in Nußdorf am Attersee | Central-Europe, Austria | Residential: single-family house | Renovation | GFA main building 301.63 m ² . | In-Use |
| Single-family House in St. Andrä i.L | Central-Europe, Austria | Residential: single-family house | Renovation | GFA main building 235 m ² . | In-Use |
| Condominium in Braunau | Central-Europe, Austria | Residential: | Renovation | Finished in 1996, GLA 90.08 m ² . | In-Use |

3.19.2. 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.

⁸⁸ Gross Floor Area

⁸⁹ Gross Leasable Area

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 2016⁹⁰.

3.19.3. HOW PERFORMANCE IMPROVEMENTS WERE MEASURED

The key indicators identified were:

- Market value [local currency]

Supporting indicators identified were:

- 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

⁹⁰ TeGoVa (2016) *European Valuation Standards* [online], available at: <http://www.tegova.org/en/p4912ae3909e49> [20/5/2016]

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 Lasi.
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, while LCC data is practically not available at all.

The value impact of the modified approach is for most 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 reasons 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 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 23 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 focussed on by IMMOVALUE: the income approach and the cost approach. Figure 24 illustrates the use of the WAPEC tool to calculate the WAF.

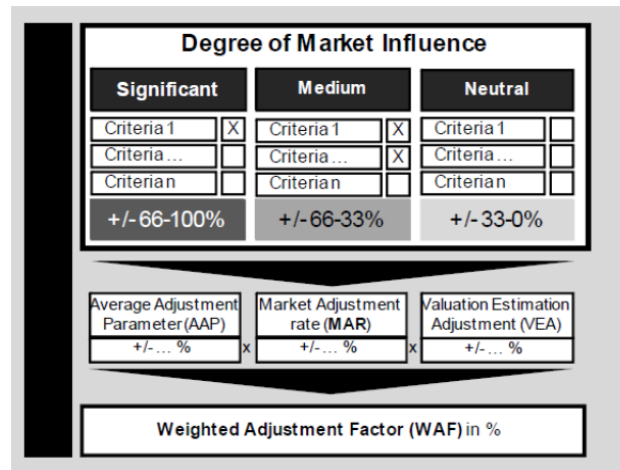


Figure 23: Overview of how the Weighted Adjustment Factor (WAF) is calculated

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) | <input checked="" type="checkbox"/> - high price elasticity <input checked="" type="checkbox"/> - high awareness of tenants for sustainability and energy efficiency <input type="checkbox"/> - omnipresence of green building issues in the media <input type="checkbox"/> - high market sensitivity for operating expenses and energy costs (especially in gross rent-orientated property) <input type="checkbox"/> - good general economic conditions <input type="checkbox"/> ... | <input checked="" type="checkbox"/> ... | <input type="checkbox"/> ... | <input type="checkbox"/> - low price elasticity <input type="checkbox"/> - tenants do not pay attention on sustainability and energy efficiency at all <input type="checkbox"/> - media does not recognise green buildings benefits at all <input type="checkbox"/> - majority of property market is not willing to pay rent premium for green buildings <input type="checkbox"/> - suffering economic situation <input type="checkbox"/> ... |
| | → Discount for non-energetic building (mainly in further developed markets) | <input type="checkbox"/> - building does not achieve energy performance standards/codes <input type="checkbox"/> - market postulate green building standards/codes <input type="checkbox"/> - high obsolescence and potential loss of occupier demand <input type="checkbox"/> ... | <input type="checkbox"/> ... | <input type="checkbox"/> ... | <input type="checkbox"/> - building achieve green building requirements <input type="checkbox"/> - market does not postulate green buildings <input type="checkbox"/> - no effect on occupier demand <input type="checkbox"/> ... |
| <div> <div>Market adjustment rate (MAR)</div> <div> <div>+/- 75-100 %</div> <div>+/- 50-75 %</div> <div>+/- 25-50 %</div> <div>+/- 0-25 %</div> </div> </div> <div> <div> <div>x</div> <div>Average adjustment parameter (AAP)*</div> <div>x</div> <div>Valuers estimation adjustment (VEA)*</div> <div>=</div> <div>→ Weighted Adjustment Factor (WAF)</div> </div> <div> <div>+/- [] [%]</div> <div>→ AAP derived from market evidence / valuers expectations due to replicable argumentation or estimation</div> <div>+/- [] [%]</div> <div>→ Valuers estimation adjustment due to probability of occurrence, uncertainty, etc. regarding the AAP</div> <div>=</div> <div>+/- [] [%]</div> <div>→ = MAR x AAP x VEA</div> </div> </div> <div> <div>Key Valuation Parameter (KVP)</div> <div>x</div> <div>[] [€/m² p.m.]</div> <div>Valuation Parameter Adjustment (VPA)</div> <div>=</div> <div>[] [€/m² p.m.]</div> </div> | | | | | |

Figure 24: 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.

CHAPTER 4 SUMMARY OF FINDINGS PER MACRO-OBJECTIVE

4.1. GREENHOUSE GAS EMISSIONS FROM BUILDING LIFE CYCLE ENERGY USE (MACRO-OBJECTIVE B1)

The first macro-objective focusses on projects which either estimate CO₂ equivalent emissions (sometimes referred to as 'carbon footprint analysis') or Global Warming Potential (GWP). A distinction can be made between carbon emissions as a result of the building's operational energy use (operational carbon) and the carbon emissions as a result of the other life cycle stages such as the production and construction of the building (embodied carbon). A specific focus alongside these could also include the potential for gaps in predicted and actual operational energy use.

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: Predicted and actual energy use, carbon footprinting;
- ENSLIC (ENergy Saving through promotion of Life Cycle assessment in buildings): Life-cycle embodied CO₂ equivalent emissions.

In addition, two cross-check studies are considered in the analysis:

- ASIEPI: large scale European study on the implementation of the EBPD-regulation in Europe;
- Database of embodied Quantity outputs (deQo): online database of material efficiency and embodied carbon of building structures (US).

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

4.1.1. OPERATIONAL CARBON EMISSIONS

→ Improvement options

The field studies revealed numerous options to reduce the operational carbon emissions. In summary, the following common improvement options were identified:

- Reduction of the net energy demand for cooling or heating, which links to the improvement of the building envelope. This includes: improved thermal insulation of the

floor, walls and windows, thermal bridge free design, windows with high performance glazing, airtight construction, etc. Performance targets formulated are limit values for net energy demand for heating or cooling (expressed in kWh/m².year) or maximum U-values for building components or a threshold value for the thermal characteristics of the building envelope as a whole;

- Reduction of the primary energy consumption of the building, which not only relates to the building envelope, but also to the performance of the technical installations. This typically includes: low temperature heating systems, on-site renewables such as PV-panels, balanced ventilation with heat recovery, etc. Performance targets are set in relation to the regional or national calculation methods (for instance, in the case of the Eco-life field study in Flanders, this corresponded with E-value E60);
- Reduction of the operational carbon emissions. This is linked to the previous item: once the primary energy consumption is known, it is a small step to calculate the carbon emissions. HQE put forward the following benchmark values for office buildings (corresponding with the French EPBD-regulation RT 2012):
 - o $\leq 25 \text{ kg CO}_2\text{eq/ m}^2\text{.year}$;
 - o $\leq 15 \text{ kg CO}_2\text{eq/ m}^2\text{.year}$;
 - o $\leq 5 \text{ CO}_2\text{eq/ m}^2\text{.year}$.
- Improvement options to increase the proportion of renewable energy source or “Low Zero Carbon technologies” in the energy production;
- Improvement options to monitor the energy consumption during the use stage.

The Energy Performance of Buildings Directive (EPBD) is of particular relevance with regards to operational carbon emissions, more in particular the national (and in some cases regional) implementation of the EPBD in the Member States. At present time, the EPBD is widely accepted and the building practice is familiar with the performance targets put forward by the EPBD and its local implementations. However, it should be taken into account that while the EPBD provides a common framework, the Member States had some freedom in its implementation and as a result, calculation methods and requirement levels differ from country to country or even from region to region. The European research project ASIEPI highlighted this issue in their study.

To respond to this, the certification schemes formulate their performance targets in reference to the national or regional calculation methodologies (for instance, in the case of BREEAM: 1% to 100% improvement in relation to the local regulation for new-build). The Skanska field study uses the same approach. If there is no such methodology in place, the majority of certification schemes require dynamic energy simulations. When this is not possible either, a checklist with “energy design features” has to be verified. While each certification scheme tends to refer to the national regulation, the benchmarks and reference values they use can differ.

Besides local regulation, performance targets and benchmarks are also derived from voluntary labels (e.g. Passive House label) or certification schemes (e.g. HQE). For HQE, BREEAM, DGNB: the benchmark/reference building differs according to the certification scheme (different % of improvement as a result).

There are no specific targets set in terms of CO₂-reduction, aside from expressions such as “Zero Carbon”. For instance, the target of the ECO-Life project is to establish zero-carbon neighborhoods. 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 CO₂-equivalents and the balancing period is one year. This means that the net amount of CO₂-equivalents released on a yearly basis should be zero.

Finally, it should be mentioned that several energy performance parameters also influence thermal comfort requirements, as for example ventilation and airtightness. Examples of thermal comfort requirements are: airtightness performance targets for passive houses (e.g. $n_{50} < 0,6 \text{ h}^{-1}$) or overheating threshold values.

→ Tools, methodologies and standards

As discussed previously, calculation methods differ among Member States. The differences are related to various aspects. The ASIEPI study provides a number of examples to illustrate this⁹¹:

- Indicator used: For instance, The Netherlands uses energy labels, Flanders (Belgium) uses E-value for new buildings;
- Building typology dependent: Performance targets, methodologies and indicators differ for residential, non-residential or public buildings. Additionally, they may differ for new-build or renovation projects⁹²;
- Energy uses considered vary in the national methods. For instance, in Flanders, lighting is not considered in the energy performance calculation of residential buildings, while it is included in the Dutch national method.;
- Functional unit: For instance, in Flanders (Belgium), energy performance of residential apartment buildings is calculated on the level of the dwelling unit instead of the apartment building;
- Approach for the estimation/measurement of energy use: the operational energy use can be based on predictions or measurements⁹².

National and regional EPBD regulations require use of different tools to calculate the energy performance, ranging from steady-state simulation tools to advanced dynamic simulation tools. As already indicated, the certification schemes (HQE, BREEAM and DGNB) in general refer to these national and regional methodologies. If there are no regional or national simulation tools available, the certification schemes require the use of dynamic simulation tools (in case of non-residential buildings). The exception is the LEED certification scheme, which requires a dynamic simulation according to American standards, for instance ASHRAE 90.1 in case of non-residential and medium-to high-rise residential buildings⁹³. Dynamic simulations are understood to produce more accurate and thus reliable energy calculations than steady-state simulations. Nevertheless, as dynamic simulations also rely on assumptions, the gap between predicted and actual energy use remains. Although, if both steady state and dynamic calculations are made using identical assumptions, then the dynamic simulations are more in line with the real energy use. This was observed in the ALTO office project ZENORA, where both steady-state and dynamic simulations were conducted to assess the operational energy use. As dynamic simulations require additional costs and time when compared to steady-state calculations, building clients do not prefer dynamic modeling. Especially, when dynamic simulations still show differences with the measured energy use.

→ Data requirements

Data requirements for energy simulations on a project level in general include the following:

⁹¹ Spiekman, M., (2010), ASIEPI – assessment and improvement of the EPBD impact – Final report part 2: comparison of energy performance requirement levels: possibilities and impossibilities

⁹² Arcipowska et al. (2014), Energy Performance Certificates across the EU – a mapping of national approaches, BPIE

⁹³ ASHRAE 90.1 (2007), Energy Standard for Buildings Except Low-Rise Residential Buildings

- *Building geometry*: obtained from the architectural drawings or derived in-situ;
- *Building or building component characteristics*: obtained from technical fact sheets, regional databases or from inspection in case of existing buildings;

On a regional level, climate data and assumptions/default values are used. Weather data at different resolutions and time intervals to support steady-state and dynamic simulations are available for major cities in Europe. Identified resources include: ASHRAE's IWEF files⁹⁴, CIBSE's TRY and DSY files⁹⁵ and Meteonorm's weather files⁹⁶. Note that this applies to weather data of reference years. Future climate projections are less easily available, see section 4.4.2 "Exposure to hazardous substances – materials' emissions and (de)construction of building components

→ Improvement options

Concerning the exposure of hazardous substances as a result of materials' emissions, the following two strategies are identified in the field studies as common options to improve the indoor air quality: selecting and applying building materials with low emission values, and limiting the indoor air concentrations of hazardous substances. Criteria relate mainly to Volatile Organic Compounds (VOCs) and aldehydes (in particular formaldehyde).

In both the renovated and new-build office projects of ALTO, the certification schemes define performance targets that relate to the selection of low emission building materials. However, different approaches can be distinguished.

The majority of the certification schemes in the ALTO office projects tend to focus on certain product types. Depending on the product type, different emission levels and standards may apply. HQE limits the scope to building materials in contact with the indoor air in occupied spaces. BREEAM also limits the requirements to key internal finishes and fittings integral to the building (wood panels, timber structures, wood flooring, textile and laminated floor coverings, suspended ceiling tiles, flooring adhesives, wall-coverings) but excludes furniture (e.g. office desks). In particular for wood-based panels (such as OSB), BREEAM uses the formaldehyde emission classes E1 and E2 as referenced in the harmonised European standard EN 13986. LEED considers the following product categories: adhesives and sealants; paints and coatings; flooring systems; composite wood and agrifiber products.

The proportion of the surface area that has to comply, depends on the desired certification scheme and the desired performance level. For instance, HQE requires a compliance for 50%, 80% or 100% of the surface area in contact with the indoor air, to acquire respectively a base level, a performant level or a very performant level rating. BREEAM on the other hand requires a surface area proportion of 100% for five out of the seven product types to acquire credits on this criterion.

Furthermore, a two-step approach can be identified in the case of HQE. In the first step, it is sufficient to assess the VOCs or formaldehyde emissions (without the obligation of meeting a threshold level) for 50% to 100% of the indoor surfaces. In the second step, TVOC and formaldehydes limit values are defined for wall, floor and ceiling coverings. The limit values for TVOC range from 2000 µg/m³ (performant level) to 1000 µg/m³ (very performant level). The limit

⁹⁴ ASHRAE. 2001. International Weather for Energy Calculations (IWEF Weather Files) Users Manual and CD-ROM, Atlanta: ASHRAE, available at: www.ashrae.org/resources--publications/bookstore/iwec2 [01/08/2016]

⁹⁵ CIBSE, 2016, *CIBSE Weather Data sets*, available at: www.cibse.org/knowledge/cibse-weather-data-sets [01/08/2016]

⁹⁶ Meteonorm, 2016, *Meteonorm software*, available at: www.meteonorm.com/ [01/08/2016]

values for formaldehydes range from 120 µg/m³ (performant level) to 10 µg/m³ (very performant level).

DGNB uses a different approach. The certification scheme sets qualitative requirements regarding the selection of low emission building materials, in the sense that it recommends the use of environmental labels (e.g. Blaue Engel), product codes (e.g. EmiCode) or testing procedures (e.g. AgBB). It does not set specific quantitative targets for the material selection and instead refers to an indoor air quality assessment of hazardous substances.

The field studies that focussed on residential buildings (Cleanair Lowenergy and Renovair), did investigate the extent to which home owners or architects want to achieve a healthy IAQ by choosing low-emission building materials. However, aside from the applicable EU regulations, Belgium has no mandatory product label that applies to all building products available on the Belgian market.

The WHO guidelines serve as a common reference for limitations of indoor air concentrations of hazardous substances. Local regulations sometimes apply also, for instance Flemish Indoor Air guidelines in the case of Cleanair Lowenergy and Renovair. In the annex of the European Standard EN 15251, an expected 'low indoor pollution level' is determined by the following criteria:

- Emissions of TVOC < 0,2 mg/m²h;
- Formaldehyde emissions < 0,05 mg/m²h;
- Ammonia emissions < 0,03 mg/m²h;
- Emissions of carcinogens < 0,005 mg/m²h;
- No odour emitting materials (dissatisfaction due to odour nuisance < 15%).

In the ALTO office projects, only DGNB stipulated threshold values for VOC and formaldehyde concentrations in the indoor air had to be verified in one or more rooms, by means of indoor air sampling methods according to ISO 16000-3 and ISO 16000-6 (see next section). The limit values for TVOC range from 3000 µg/m³ (minimum level to achieve credits) to 500 µg/m³ (highest level). The limit values for formaldehydes range from 120 µg/m³ (minimum level to achieve credits) to 60 µg/m³ (highest level).

Regarding the exposure to hazardous substances during the (de)construction of building components, DGNB makes a clear distinction between the *emission* and the *content* of hazardous substances. Regarding the content (which can be released during (de)construction of the building components), the certification scheme has defined criteria for a wide range of building materials: foundations, floor structure, external and internal walls, ceiling, roof and underground car parks. Requirements are defined for four quality classes and relate to VOC and heavy metal content, dangerous compounds etc.

→ Tools, methodologies and standards

In the **ALTO office projects**, different methodologies and standards are used and referred to by the certification schemes.

HQE refers to the ISO 16000 series, which can be seen as the key reference standards regarding indoor air quality assessments. Regarding the laboratory testing of VOC product emissions, the emission test chamber method and the emission test cell method as outlined in ISO 16000-9 and ISO 16000-10 apply. In addition, HQE refers to national evaluation methods for VOC and

formaldehyde assessments in France (AFSSET), Finland (M1 classification scheme) and Germany (AgBB, GUT, EMICODE).

DGNB uses the German Building Product Testing and Evaluation Scheme developed by AgBB.

LEED considers the German evaluation methods to assess VOC concentrations for certification projects outside the US, although in general, it refers to American standards, such as the South Coast Air Quality Management District (SCAQMD) Rules and Green Seal Standards.

BREEAM refers to a number of standards, depending on the type of floor, wall or ceiling product.

Regarding the assessment of formaldehyde, both HQE and BREEAM specifically highlight the European standards EN 717 and EN 120, in which methods are specified to determine the content of formaldehyde in wood-based panels or its release from wood-based panels (e.g. OSB panels).

The **Officair study** not only focussed on the building materials and products used for floor, wall or ceiling coverings, but also performed laboratory tests of office furniture. This included common office furniture such as an office desk, lap-top, office chair, wall board, printer and projector but also common cleaning products such as an all-purpose cleaner and screen cleaner. The results indicated that the wall board and office desk have the largest amount of total emissions. Considering that these pieces are quite common in an office setting and typically account for several m² in an office environment, these two are the most important polluters in offices.

The methodologies mentioned to this point focus solely on product emission tests in a laboratory environment. The ISO 16000 series also includes standards with specifications for measurement tests in actual buildings. Regarding **in-situ measurements** of formaldehyde, VOC and TVOC concentrations in indoor air, the active sampling methods as specified in ISO 16000-3 and ISO 16000-6 are used. In the DGNB scheme, the indoor TVOC concentrations are determined based on these standards. DGNB puts more emphasis on these in-situ measurements than the other schemes, which cover mostly laboratory tests of building products: DGNB stipulates that measurements and chemical analyses must be conducted within four weeks after building completion and before furniture is installed. The number of rooms, which have to be measured, depends on the total number and variety of the rooms in the building.

The research projects (Officair, INSULatE, Cleanair lowenergy and Renovair) not only conducted measurements for TVOC, VOCs and aldehydes (compounds typically related to indoor sources of pollution), but also O₃, CO₂, NO₂, PM_{2.5} and PM_x concentrations (substances typically related to outdoor sources). The methodologies used are listed for each field study in ANNEX 1 Catalogue of field studies. The different scope and building aspects covered are summarised in Table 44.

Table 44: Overview of the different scope and building aspects covered in the field studies

| Building aspects | Scope | Methodology | Field study |
|---|---|---------------------|---------------------|
| Interior finishings: <ul style="list-style-type: none"> - Wood panels: particleboard, MDF, OSB... - Timber structures: glued laminated timber - Wood flooring - Resilient, textile and laminated floor coverings: vinyl/linoleum, cork and rubber, carpet, laminated wood flooring - Suspended ceiling tiles - Flooring adhesives - Wall coverings: wallpapers, textile or plastic wall-coverings, ... | <ul style="list-style-type: none"> - Formaldehyde - Formaldehyde - Formaldehyde - Formaldehyde - Formaldehyde, asbestos - VOCs - Formaldehyde, VCM | Product testing | BREEAM |
| Interior finishings: <ul style="list-style-type: none"> - Adhesives and sealants - Paints and coating - Flooring (except mineral-based finish floorings) - Composite wood (= building elements, not furniture or equipment) | <ul style="list-style-type: none"> - VOCs - VOCs - VOCs - Formaldehyde | Product testing | LEED |
| Interior finishings: <ul style="list-style-type: none"> - Interior surfaces (walls, floors, ceilings) (construction materials in direct contact with indoor air) - Paints and varnishes | <ul style="list-style-type: none"> - Formaldehyde, VOCs, CMRs, wood treatment - Formaldehyde, VOCs | Product testing | HQE |
| Representative room, taking into account seasonal variations (winter and summer periods) | NO ₂ , CO, Benzene, formaldehyde, PM _{2.5} and PM ₁₀ , Radon, TVOC | In-situ measurement | |
| Representative room, within four weeks after completion | Formaldehyde, TVOC | In-situ measurement | DGNB |
| Representative room during occupation, taking into account seasonal and spatial variation | VOCs, TVOC, aldehydes, particulate matter (PM _{2.5} , PM ₁₀), O ₃ , NO ₂ | In-situ measurement | Officair |
| Equipment: <ul style="list-style-type: none"> - Furniture (typical office equipment) and cleaning products | TVOC, SVOC, aldehydes, PM ₁₀ , O ₃ , Ultrafine Particles (UFP), carbonyl | Product testing | |
| Living room of single family house (new-build) | VOCs, TVOC, aldehydes, PM _{2.5} , PM _x , CO ₂ | In-situ measurement | Cleanair, Lowenergy |
| Living room of single family house (renovation) to measure impact of following renovation measures: Upgrade of windows; Façade insulation; Wall insulation; Floor insulation; Roof and ceiling insulation; Wall treatment against rising damp; Thorough energetic renovation; upgrade to mechanical ventilation system | VOCs, TVOC, aldehydes, PM _{2.5} , PM _x , CO ₂ | In-situ measurement | Renovair |

| | | | |
|--|--|---------------------|----------|
| Living room of apartment unit (renovation) | VOCs, TVOC, formaldehyde, PM2.5, PM10, CO2, CO, radon, NO2 | In-situ measurement | INSULatE |
|--|--|---------------------|----------|

→ Data requirements

Data requirements for these aspects of the macro-objective include information on the building products used for the internal finishing of the floors, walls and ceilings: product type, quantities and technical characteristics. This concerns data on the emissions and content of hazardous substances in building products.

The field studies indicate a variety in the availability of and accessibility to this data in the building practice and among the Member States.

The Skanska projects pointed out several databases of building products in the Scandinavian countries, which focus on collecting this kind of data. Examples quoted by the Skanska Business Units include: Basta online, BVB and Sundahus in Sweden, and ProductXchange in Norway. The Finnish M1 classification system in Finland and the different initiatives in Germany already mentioned also indicate the existence of such databases in Finland and Germany.

When emission or content data is not available for a building product, laboratory tests by an accredited party are necessary.

→ Processes and actors

Table 45: Processes and actors – product emissions

| Methodology | Project stage | Lead actor | Supporting actor |
|--|--|--|---|
| Selection of low-emitting building materials | Concept design, developed and technical design, construction | Architect | Environmental consultant, manufacturer During construction: contractor |
| Product testing | Construction | Accredited third party (laboratory) conducting the tests | Manufacturer, contractor |
| In-situ measurements of IAQ | Hand-over and close-out | Third party conducting the assessment | Contractor, architect, environmental consultant |

Regarding the selection of low-emitting building materials and the assessment of the product emissions, the architect must depend on emission data on building products. This data is typically provided by the manufacturer in the technical information sheets of the product. Labels or classification systems provide more practical support to the architect during the concept design. Otherwise, laboratory tests by accredited third parties might be necessary, which implies an additional cost.

Regarding in-situ measurements of the IAQ, the timing of these measurements can influence the results significantly. In particular, if measurements are done before or after the installation of furniture, or pre-/post-occupation. For instance, in the case of TVOC concentrations, DGNB stipulates that the measurements have to take place no more than four weeks after building completion and before furniture is installed. Emission testing of office furniture in Officair however indicate that office furniture can be an important source of hazardous substances. Officair also indicated seasonal variations of the results (i.e. different concentrations in winter compared to the summer period). In-situ measurements can be interpreted as additional quality assurance. The measurements almost always imply an extra cost, as a third party has to conduct them.

→ **Lessons learned**

Selection of 'healthy' building materials is important and is generally considered as a priority over increasing ventilation rates. It is supported by three classes of measures:

- Imposed in product policy : e.g. EU Construction Product Regulation, Belgian regulation on VOC emissions from flooring products, the German AgBB and the French labelling for indoor construction products;
- Imposed in national building codes: D2 National Building Code of Finland, Ministry of the Environment, Department of Built Environment;
- Encouraged by voluntary product labels and building certifications: e.g. DGNB, LEED, EU Ecolabel, M1, Blue Angel and NaturePlus, etc.

Targets and application fields, associated to these measures, are different per instrument:

- ranging from threshold levels to the bann of a chemical;
- ranging from specific building product types (e.g. only flooring and glues in the Belgian Decree) to a broad field of application (e.g. the German AgBB, French labelling system) with different ambition levels on reducing emissions: limited (French labelling and EU Ecolabel) to very extensive restrictions (M1 label and AgBB).

The determination of the concentration levels of hazardous substances can be performed using different analytical methods and techniques, and can be expressed in various units. The ISO-16000 is identified as key standard in this regards. A clear distinction can be made between approaches which imply product emission testing and approaches which focus on in-situ air measurements. In the ALTO office projects, BREEAM and LEED focus on the former, while DGNB emphasises more on the latter. HQE covers both approaches.

In the case of product emission testing, the scope of the assessment of hazardous substances is largely focussed on VOCs and formaldehyde. This initial scope is enlarged for certain product groups: for instance, asbestos in case of ceiling tiles, wood treatments, or Vinyl Chloride Monomer (VCM), which is related to PVC products. HQE puts additional emphasis on Carcinogenic, Mutagenic and Reprotoxic substances (CMRs) as defined in the European CLP Regulation. In general, building aspects considered include the building materials related to interior floor finishings, wall or ceiling coverings. The Officair field study is an exception, as it specifically targets the building equipment: more in particular, the typical furniture, objects and cleaning products used in offices. As a result, the assessment does not only include VOCs and formaldehyde but other substances as well, such as carbonyl, ultrafine particles (UFPs), particulate matter, ozone and nitrogen dioxide, as these are understood to be linked to certain product groups such as printers or cleaning products.

In the case of in-situ air measurements, it is observed that the scope of the assessment of hazardous substances is broader. In addition to formaldehyde and VOCs, the following pollutants

are included in the assessment of at least one field study: CO, CO₂, NO₂, O₃, particulate matter (PM_{2.5}, PM_x and PM₁₀) and Radon. Furthermore, the total VOC-level (TVOC) can be calculated as well. Based on the experience of the field studies, it is clear that the choice of the timing of the in-situ measurements is very important to have representative and meaningful results. For instance, in Officair, seasonal variations in winter and summer were observed. An issue is whether in-situ IAQ testing is carried out for unoccupied (post-completion) or occupied spaces. DGNB specifically requires an in-situ measurement within four weeks after completion, before occupation of the building in order to be representative of the building itself (without equipment). Furthermore, the location of the assessment has an influence as well. In Officair, spatial variations were observed in the building itself: IAQ-measurements on lower storeys differed significantly from IAQ-measurements on upper storeys as a result of external pollution on street level. Both DGNB and HQE require that the in-situ measurements be conducted in a representative room (for instance, office rooms in office buildings). In the field studies that focussed on residential buildings, measurements were conducted in the living rooms.

In the majority of the field studies, substances such as VOCs and formaldehydes are typically related to “indoor” sources of pollution, while substances such as O₃ and NO₂ are identified as “outdoor” pollutants. However, this is not always the case, as illustrated in the Officair assessment of office equipment, where particulate matter was linked to an indoor source (i.e. printers). This indicates that caution is needed when classifying certain hazardous substances as “indoor” pollutant or “outdoor” pollutant, just on the basis of its type. The ratio of indoor and outdoor concentrations of pollutants (I/O-ratio) can be a supporting indicator in this regard. However, as this indicator requires not only indoor but also outdoor measurements, it seems limited to research studies and does not seem feasible to assess in a common building project.

Regarding the experience from the certified projects of ALTO, it is observed that the HQE requirements are not difficulties to attain. In particular, the two-step approach of the HQE targets (first step: require an assessment without quantitative targets; second step: define quantitative performance targets or benchmarks) seems to be successful in the sense that it allows the building practice (in particular product manufacturers) to become familiar with the assessment methodology.

The approach of HQE and DGNB distinguishes itself from the other certification schemes as it requires in-situ measurements (however, it is recently introduced in BREEAM assessments too). Only a few field studies however provided results from measurement of VOC emissions post-completion. Such post-completion measurement were conducted in one of the ALTO office projects, 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 city center entered the building. Furthermore, the measurement conditions were not ideal: carpets as well as crawlspaces and ventilation channels were not cleaned well, windows were opened and as result external pollution entered the building before the ventilation’s commissioning.

It is difficult to identify the approach which is best in terms of minimising risk of exposure. The majority of criteria in each of the certification schemes target indoor finishings, but there is no clearly defined priority list. This should clearly relate to the goal of the assessment: does the assessment target the building, the interior or the equipment? The field studies indicate a strong relationship between the building/equipment aspects that are considered, the assessment method and the scope of the hazardous substances. For instance, when furniture and room equipment is

considered, it makes sense to not only consider VOC and formaldehyde, but other substances as well such as UFPs or PMs (which are emitted by printers) or ozone (in case of cleaning products). In addition, it is difficult to capture the influence of user behaviour and context factors (for instance the location of the building and possible external pollution related to it), although these factors can have a significant impact on the indoor air quality, despite dedicated efforts in applying low-emission materials, an adapted ventilation strategy and measures for air intake.

→ Indicator options

Table 46: 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 | | | |
| 4.2 Hazardous substances – source control | | | | | | | |
| Indoor air pollutant concentrations | µg.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 |
| Rating or classification system for building materials | Emissions class, R Value and/or µg.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, SUNDAHUS (Sweden)) | - | FS AR CC |

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

| 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 | | | |
| 4.2 Hazardous substances – source control | | | | | | | |
| I/O ratio (indoor/outdoor ratio of pollutant concentrations) | [dimensionless] | B1-7: Use | In-use | Ventilation | EN 13779 | VOCs, TVOCs, aldehydes, particulate matter (PM2.5, PMx, PM10), CO2 | FS |

4.1.2. MOISTURE AND MOULD

→ Improvement options

Improvement options focus on the prevention of mould and moisture causes and resulted damage.

In the refurbished ALTO office project, mould and moisture were measured using the French standard AFNOR XP X 43-401 for the assessment. It provides a range of recommended values for bacteria and fungi concentrations in the case of office buildings (see Table 47).

Table 47: Performance targets for bacteria and fungi concentrations in offices, expressed in Colony Forming Units (CFU) per m³ (source: French standard AFNOR XP X 43-401 – annex A.4 (1998))

| | Bacteria concentrations (CFU/m ³) | | Fungi concentrations (CFU/m ³) | |
|---------------|---|---------|--|---------|
| | offices | outside | offices | outside |
| percentile 5 | 95 | 25 | 3 | 17 |
| percentile 50 | 320 | 70 | 6 | 61 |
| percentile 95 | 1020 | 281 | 45 | 257 |
| maximum | 3150 | 860 | 710 | 675 |
| minimum | 15 | 15 | 1 | < 1 |

Cleanair Lowenergy referred to the Flemish Indoor Environment Decree of 11/06/2014, which puts forward guideline values for biological parameters including micro-organisms and fungi.

Table 48: Guideline values for biological parameters according to the Flemish Indoor Environment Decree of 11/06/2014 (source: Flemish Government (2014))

| Compound / factor | Guideline value |
|----------------------|--------------------------|
| house dust mite | ≤ 0.2 mg guanine/g dust |
| cockroach | < 1 per building |
| micro-organisms | ≤ 500 CFU/m ³ |
| mites | |
| - In floor covering | ≤ 10/g dust |
| - In bed / furniture | ≤ 100/g dust |
| rat / mouse | < 1 per building |
| fungi | ≤ 200 CFU/m ³ |

The field studies that cover residential refurbishment projects (i.e. Renovair and INSULatE) emphasis on qualitative criteria and not only on quantitative target values, for instance visual observations of mould and moisture damage.

→ Tools, methodologies and standards

In the Cleanair, Lowenergy biological agents were assessed by using air samples and surface samples of settled dust. In Renovair and INSULatE, surface samples were collected but no air samples. In Renovair, a visual inspection of fungi and moisture problems was conducted using a walk-through survey based on a checklist for building inspection that was developed under the

framework of the HITEA study. The microbial pollutants addressed in Cleanair, Lowenergy were bacteria, fungi and yeast. The microbial pollutants addressed in Renovair and INSULAtE were bacteria and fungi.

Regarding the air samples, sampling was performed in the living room, the bedroom as well as in the garden; at school, sampling was performed in each selected classroom, as well as on the playground. All samples were collected during the same house or school visit. Samples were collected in the middle of the room, at a height of 1-1.5m. The analysis of the samples were conducted according to ISO 21527-1 in case of the total fungi and yeasts, and ISO 4833 in case of the total bacteria.

Regarding the surface samples of settled dust, houses received a post package, containing (1) two Petri dishes with a surface of 15 cm for houses; (2) a letter with instructions and explanations (see Annex); (3) a questionnaire for biological measurements. The participants were instructed to open the Petri dishes and to install two halves in the living room and two halves in the bedroom for residences. The Petri dish should be installed at a height of 1.5 m, be out of reach of children and pets (the inside of the dish should not be touched), and should not be closer than 1 meter to a window or door opening. When the dishes were installed, a printed document saying *'Please don't touch or move'*, was installed next to it. Any incident should be reported on the questionnaire for biological measurements. The samples were exposed for one week (7 days). The sampling analysis of the yeast and fungi and the total bacteria was performed in agreement with ISO 21527-1145 and ISO 4833146 respectively.

The approach of the building inspection on mould and moisture issues, which was conducted in the HITEA study and formed the basis of the survey used in Renovair, is described in a publication of Ulla Haverinen-Shaughnessy. In a first step, a questionnaire survey was circulated to school principals and the responsible persons for the maintenance of their school building (in the case of HITEA, school buildings but the approach can easily be applied on other building types as well) to screen the buildings on moisture damage and dampness problems. The questionnaire contained ten key questions on current and past dampness, moisture and mould observations and collected background information on building and ventilation characteristics. In a second step, on-site building inspections were conducted by trained research personnel that included walkthroughs with pre-designed checklists and non-destructive measurements such as hand-held moisture detection, relative humidity, temperature and CO₂ monitoring.

A comprehensive framework for mould and moisture assessments in existing buildings with an overview of possible measurement methods is provided by a publication of Haverinen-Shaughnessy et al. In addition to the non-destructive techniques already mentioned (air and surface sampling, accompanied by surveys or walkthroughs), destructive methods are mentioned if during the inspection there were locations suspected to have new damage, or if the damage was suspected to be repaired unsatisfactory. Furthermore, the importance of paying attention to timing and location of samples was highlighted (for instance measurements during winter and summer). Finally, the author points out the importance of continuous maintenance as the best follow-up practice to ensure the success of repair measures taken during the building lifespan.

→ Data requirements

Data of concentrations of biological agents is collected on-site using air or dust sampling.

Data of building characteristics (with an emphasis on the building construction, building envelope and technical installations such as the ventilation system) can be collected during an on-site

inspection in combination with available documentation of the building, or through surveys with the building manager or building occupant.

→ **Processes and actors**

Table 49: Processes and actors – Moisture and mould

| Methodology | Project stage | Lead actor | Supporting actor |
|------------------------------|---------------------|--|--|
| Survey | In-use | Building manager | Occupant |
| Walkthrough checklist | In-use | Trained professional for building inspection (architect, contractor) | Occupant, building owner, building manager |
| Air and/or dust sampling | In-use | Accredited third party | Occupant |
| Follow-up during maintenance | In-use, maintenance | Building manager, occupant | - |

The field studies analysed focussed mainly on remediation of mould and moisture issues. A variety of methods and techniques that can be applied during the in-use phase of the building were identified. The methods listed were already discussed in the section “Tools, methodologies and standards”.

Nevertheless, building actors such as architects and contractors have an important role during the design and construction of the building to prevent mould and moisture issues, although the field studies did not specifically provide evidence regarding this.

→ **Inventory of lessons learned**

Measurement of damp and mould is a relatively new area, and it appears that test methods to evaluate levels in-situ are relatively undeveloped for widespread use. Some Member States have run extensive programmes to tackle problems in existing buildings, for instance the national mould and moisture programme in Finland. However, it appears to have focussed more on training and guidance.

With regards to renovation projects, according to the Renovair data, thermal bridges present before the renovation are in some cases even more pronounced after renovation. The airtightness 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 Finnish moisture and mould programme.

Finally, the publication of Haverinen-Shaughnessy et al.¹⁴⁸ pointed out that in some of the case studies, no improvement could be observed in IAQ or occupant health, even if technical remediation measures to address mould and moisture issues had taken place successfully. Possible reasons that are quoted include: 1) all damage may not have been addressed adequately; 2) IAQ or health may not have been perceived improved regardless of remediation; and/or 3) the methods used may not have been sensitive/specific enough to detect such improvement within the assessment period.

→ Indicator options

Table 50: 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 | | | |
| Concentration of biological agents (fungi, yeast and total bacteria) | CFU/m ³ CFU: Colony Forming Units | B1-7: Use | In-use Handover and close-out Refurbishment In-use | In situ air quality | French standard: AFNOR XP X 43-401 | - | FS |
| Inspection classification of dampness and mould in building structures | Rating or classification | B1-7: Use | | Internal conditions | Member State rating systems e.g. Nordic proposal, classes 1-4 | - | CC |

Supporting indicators

Table 51: Long list of macro-objective 4a supporting 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 | | | |
| Temperature | K | B1-7: Use | In-use | Internal conditions | In-situ measurements | - | FS |
| Relative Humidity | % | B1-7: Use | In-use | | | - | FS |
| Indoor CO2 concentration | ppm | B1-7: Use | In-use | | | - | FS |

Resilience to climate change (macro-objective B5)".

Regarding the macro-objective B1, the EPBD-directive and the fact that the building practice is quite familiar with operational energy assessment, data availability does not pose a difficult challenge.

→ Processes and actors

Currently, operational energy calculations seem to be common practice in the built environment. To comply with national EPBD-regulations, an accredited energy expert might be required. The energy simulations are carried out by these energy experts or other members of the building team such as environmental consultants or technical engineers. The architect and technical engineers are key contributors as they lead the design or technical study which has a high impact on the final energy performance.

Key project stages are:

- The design stage, with initial design options and a preliminary energy calculation;
- The developed and technical design stage, with final design options;
- Construction stage, where the design assumptions are verified and might be subject to changes;
- Hand-out and delivery, where the final energy calculations are submitted;
- In-use stage, where actual energy use can be monitored and compared to the initial energy calculations.

Note that steady-state simulations are typically conducted in the design stage, while dynamic simulations are performed in the technical design, when more design choices are taken.

Other project actors can have an important role in the process as well. Examples identified in the field studies are:

- *Building clients*: they set the ambition in the early project stages (e.g. ALTO field studies);
- *Contractors*: they propose the final material selection and are responsible for the quality of construction (e.g. airtightness, correct installation of insulation);
- *Users and inhabitants*: user behaviour and (in)correct operation during the use stage can cause gaps between predicted and actual energy use. Adequate maintenance is needed to ensure the performance during operation (e.g. Eco-life).

→ Inventory of lessons learned

Based on the field study analyses, a very clear distinction can be made in macro-objective B1 "Greenhouse Gas emissions from a life-cycle perspective" between the assessment and implementation of the operational carbon emissions and the embodied carbon emissions.

Regarding operational energy, a clear regulatory framework is identified in the form of the EPBD and its recast. As a result, operational energy calculations are common practice in Europe. The field studies analysis indicated that clients could have high ambitious targets regarding energy performance. Certification schemes refer to the national approaches, although the benchmarks/reference buildings could differ depending on the certification scheme.

Dynamic simulations can be used for energy calculations, but when compared to steady-state simulations, it has to be taken into account that they are more complex, require more skills, efforts and likely result in extra costs, which can be quite significant, depending on the nature of the building and the objectives of the calculation. While these calculations can be more accurate, as they can integrate other energy uses and can cover a broader scope, the gap between predicted and actual energy use is still very likely as it still requires assumptions regarding aspects such as building use and occupation. Instead, dynamic simulations might make more sense to address thermal comfort and overheating issues, as internal heat gains and solar gains are better captured/calculated in dynamic simulation than steady-state simulations. If dynamic simulations are used more for energy calculations, it is important to provide specific guidelines to clearly define the assumptions in order to minimize the gap between predicted and actual energy use.

In the field studies, quality assurance tests are identified, such as airtightness tests or thermographic scans. With regards to these quality assurance tests, experience from project actors (in particular the Eco-life project and the ALTO projects) point out the following attention points:

- Depending on the timing of the test, it might be difficult to steer improvement. For instance, thermal bridges discovered during a thermographic scan at the end of construction work might require too much effort to correct at that stage;
- Timing of the test: it can be difficult sometimes to execute valid practical tests due to the measurement error or other issues such as weather conditions;
- Quality assurance tests are likely to involve a third party and thus imply extra costs.

→ Indicator options

Table 25: 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 | | | |
| B1a. Operational energy use and GHG emissions | | | | | | | |
| Operational carbon emissions | Kg CO ₂ eq/m ² GFA.yr | B6 Operational energy | Concept design Technical design Construction In-use | Energy use 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 ⁹⁷ | - | FS CC |
| (operational) Primary energy consumption | kWh/ year; normalised per m ² GFA | B6 Operational energy | Concept design Technical design Construction In-use | Energy use 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 regulations or certification schemes | FS CC |
| | E-value | | | | EPBD in Flanders, using Steady-state simulations | | FS |
| | Energy label | | | | EPBD in selected MS (e.g. The Netherlands) Steady-state or dynamic simulations | | FS |
| Reduction of energy consumption | % compared to requirements of regional/national method | B6 Operational energy | Concept design Technical design Construction In-use | See “primary energy consumption” | BREEAM | According to national and regional regulations or certification schemes | FS AR |
| Measured energy consumption | kWh/m ² GFA.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 |

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

⁹⁷ Greenhouse Gas Protocol (2012) *Greenhouse gas protocol*, [online] available at: www.ghgprotocol.org/ [Accessed 20/5/2016]

Table 26: Long list of macro-objective 1 supporting 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 | | | |
| B1a. Operational carbon | | | | | | | |
| Proportion of renewable primary energy production | % (kWh.year) | B6 Operational energy | Technical design In-use | Renewable energy generation technologies | EN 15603 | - | FS |
| Net energy demand for heating | kWh/m² floor.yr | B6 Operational energy | Concept design Technical design Construction In-use | Net energy demand for heating | EN 15603 | - | FS |
| Net energy demand for cooling | kWh/m² floor.yr | B6 Operational energy | Concept design Technical design Construction In-use | Net energy demand for cooling | EN 15603 | - | FS |
| Thermal insulation level of the building envelope | U _{average} [W/m².K] | B1-7 Use | Concept design Technical design Construction | Weighted average U-value of building envelope and its components | EN 15603 | - | FS |
| | K-value | B1-7 Use | | Similar to U _{average} , but taking into account form-factor of building (compactness) | Regional requirements (Flanders, Belgium) | - | |
| Baseload demand | 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 |
| Airtightness | V50 [m³/h] | B1-7 Use | Construction Handover and close-out Construction Handover and close-out | Air leakage of the building envelope | Pressurization test according to EN 13829 | test performed at 50Pa | CC |
| | v50 [m³/m².h] | B1-7 Use B1-7 Use | | | | test performed at 50Pa; normalized by surface area of building envelope | CC |
| | n50 [m³/m³.h] | | | | | 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)

4.1.3. EMBODIED CARBON

→ Improvement options

Improvement options identified to reduce the impact of carbon emissions, relate to the optimization of the building components and/or construction process. Common options include a leaner design of the load-bearing structure, adapted material selection for particular building components or process optimization (for instance, transport distances). This implies the comparison of different options to a baseline scenario.

In the certified projects, there are no explicit targets or ambitions set for embodied carbon. Only in the case of DGNB in the CBK II-project, a criterion was dedicated to Global Warming Potential. Otherwise, it is included implicitly in criteria of the certification schemes related to environmental impact assessments of buildings and building materials.

The Skanska group formulates stepwise performance targets: 1) perform a carbon footprint calculation; 2) achieve a 25% CO₂-reduction; 3) achieve a 50% CO₂ reduction. However, several Skanska business units reported that the second and third 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% CO₂-reduction, although it has been achieved for infrastructure projects.

The Skanska performance targets are relative performance targets. Based on the field studies analysed, there seem to be no commonly accepted benchmark values that can function as absolute performance target values. A publication from De Wolf et al.⁹⁸ indicates a range of 150–600 kg CO₂eq/m²GFA for embodied carbon emissions of building structures, which provides a first lead.

→ Tools, methodologies and standards

The field studies indicate a wide variety of tools that can be used to assess embodied carbon. The majority of these are based on Life Cycle Assessment (LCA) methodologies.

The ENSLIC field study trialed a simplified LCA- methodology, based on the LCA-standards ISO 14040 and ISO14044. The simplifications were:

- A limited number of life cycle stages were considered, more specifically the product stage (raw materials acquisition, transport of the raw materials to the manufacturer and manufacturing process) and the use stage (operational use in the building);
- Only one impact category, climate change (global warming), was selected;

The ENSLIC distinguishes three categories of LCA-tools, depending on the complexity:

- Basic: Basic calculations in Excel sheets with simple input and output flows 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.
- Advanced: Comprehensive LCA tools such as SimaPro, Gabi, etc. Extensive experience is needed to handle these software applications on a building level. These tools demand a

⁹⁸ De Wolf, Yang, Cox et al. (2015) *Material quantities and embodied carbon dioxide in structures*, Engineering sustainability paper 1500033

high level of training and profound understanding of LCA models and they might not be suitable for application in early design phases.

In the Skanska field study, a wide variety of tools were observed. The Skanska Group has its own group-wide carbon footprinting tool (the Skanska AB tool): an excel-spreadsheet linked with the company's cost estimation tools. The tool is based on the one used by the Skanska Business Unit (BU) in Sweden: ECO2/Anavitor, which is developed by the Swedish Environmental Research Institute (IVL)⁹⁹. Skanska Norway uses the Norwegian government's carbon calculation tool (Klimagassregnskap¹⁰⁰, (v1 was launched in 2007, current version is v5)), Skanska UK uses LCA/LCC tools (i.e. the advanced LCA-tools such as Gabi and SimaPro) and Skanska Finland trialed the use of BIM (Building Information Modeling). In general, Skanska's BUs use the tool as required by the client or the tool that is common in the national or regional context.

Finally, a study by the MIT-university on the embodied carbon emissions of building structures¹⁰¹ indicates that the calculation required for the embodied carbon assessment can actually be rather straightforward. More precisely, the embodied carbon of a building material or component is the result of 1) the product of structural material quantities, and 2) the embodied carbon coefficients. The material quantities are included in the bill of materials (composed by the architect, structural engineer or contractor). The embodied carbon coefficients have to be obtained from LCA-inventories or other databases (see next section).

A second observation is the fact that the scope and assumptions used for the embodied carbon calculations differ significantly. This is evidenced in both the ENSLIC and the Skanska field studies. The most important differences are the life-cycle stages covered and the building components included. With regard to the life-cycle stages, the majority of the embodied carbon calculations in ENSLIC focussed on the product stage (raw materials acquisition, transport of the raw materials to the manufacturer and manufacturing process) and use stage, while the MIT-study only considered the product stage and the construction process stage (transport to the building site and the construction process). In Skanska's practice, it even differs on project-basis, as it is largely influenced by the wishes and requirements of the client. With regard to the building components, there is a focus on the building's structure as it has the most significant contribution of the total carbon emissions, but again, this depends on the practitioner or the project. In some cases, other building components are included as well such as facades (such as glass facades of office buildings) or installations (such as PV-panels¹⁰²). In fact, the choice of the building components to be included in the calculation can have an influence on the life cycle stages that have to be considered. When focusing on structures, it makes sense to only include the product stage and the construction stage. Another difference is the choice of the functional unit (more in particular the lifespan to be assumed) and the choice of databases and tools as already indicated. The choice of the functional unit and the databases and tools that are used for the assessments not only depend on the practitioner but also on the project to be assessed.

⁹⁹ Anavitor (2016) Anavitor [online], available at <http://www.anavitor.se/> [20/5/2016]

¹⁰⁰ Klimagassregnskap (2016) Klimagassregnskap, Available at <http://www.klimagassregnskap.no/> [20/5/2016]

¹⁰¹ De Wolf, C. and Ochsendorf, J. (2014) *Participating in an Embodied Carbon Database. Connecting structural material quantities with environmental impact*. The Structural Engineer, 2 (February), pp. 30-31.

¹⁰² Fjeldheim, H., Kristjansdottir, T., Sørnes, K., (2015), *Establishing the life cycle primary energy balance for Powerhouse Kjørbo, Sustainable cities and buildings*, Copenhagen 20-21 August 2015

→ Data requirements

Regarding data requirements, a distinction can be made between (carbon) emission data and material quantities.

Carbon emission data is obtained from generic or local databases. Skanska's group-wide tool uses the "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. This can differ depending on the client's wishes and the regional or national context: ranging from generic LCI data available in LCA-software such as SimaPro (e.g. ecoinvent) or specific data from Environmental Product Declarations (EPDs) or local databases (for instance, emission data provided by the Swedish Environmental Research Institute IVL in Sweden or the national web based tool klimagassregnskap in Norway).

The availability of consistent, reliable and accurate databases with emission data on national (or regional) level are identified as a barrier. In addition, as there is a lack of common guidelines, databases use different assumptions and hinder the comparison of results. Current databases (national initiatives: German, Netherlands, other initiatives: ICE or even private initiatives: Ecoinvent) could serve as starting point, but they might not be up-to-date anymore and/or have a limited geographical scope. This points out the need for a common methodology on European level but with (open-source) databases on regional or local level. The Commission (more specifically DG ENV) is working on this aspects in the framework of PEF (Product Environmental Footprint) and OEF (Organisational Environmental Footprint).

Material quantities are obtained from cost estimations, bill of materials, BIM, discussions with designers and contractors, or literature sources. In practice, a combination of these sources is most often used. For the as-built situation, BIM-models are usually a reliable source. Quality assurance and data verification are, however, highlighted as a point of attention. This relates primarily to differences of the design compared to the as-built situation.

→ Processes and actors

Based on the field study analysis, current building practice is not very familiar with embodied carbon assessments as it is not widely applied yet.

The Skanska projects in particular demonstrate how it can be embedded in the building practice. Typically, it is applied in two stages, depending on the stage of entry. First, a preliminary carbon footprint is carried out, based on the information provided from the client (targeted at the major building components: steel, concrete, windows). This preliminary study is then used to optimise the design. Secondly, a final carbon footprint is calculated in a later project stage (e.g. developed or technical design, or during construction) to be compared to the results of the initial calculation.

When carbon footprinting is applied, there is an important link identified with specific building actors, more in particular the (main) contractor or structural engineer.

In the Skanska projects, the contractor has an important role as it is the main provider of the material quantity data. The tools used for the embodied carbon calculations are as much as possible linked to the tools already used by the contractor such as cost estimations, the bill of quantities and BIM-tools to embed it as much as possible in the existing practice and as a result, decrease the complexity level and extra skills needed. Further elaborating this link with existing software tools (in particular BIM-tools) is pointed out as a possible way forward. In the MIT-study, the carbon footprint is limited to the building's structure and it is embedded in the practice of the

structural engineer, by linking it to the structural design and the related structural material specifications. Otherwise, as evidenced in the ENSLIC-study, embodied carbon assessments can be a skill-intensive exercise, requiring skilled LCA-practitioners.

→ **Inventory of lessons learned**

With regards to the embodied carbon emissions, a lack of common methodology or regulation on European scale is identified with instead a large variation of databases (both in terms of quality as geographical availability). Carbon footprinting is not common practice and still perceived as a skill-intensive task.

Carbon footprinting is a useful tool for benchmarking of single projects in the sense that it allows to compare different design options to the initial baseline situation and to express the improvement in terms of kg CO₂eq reduction. It however requires common specifications with regards to the life cycle stages and building components considered, databases and tools used, etc in order to allow for such comparisons. This highlights the need for a methodological framework with common guidelines or regulation regarding carbon footprinting.

Furthermore, the field studies analysed indicate that the reduction of carbon emissions is not usually the main driver to conduct related improvement measures. Cost-saving or construction process optimization tend to be more decisive reasons. There is no real incentive to calculate embodied carbon, aside from financial (cost, material reduction) or other (process optimization) incentives. Again, there is a need for regulation or standardization concerning this fact.

Another barrier identified, is the fact that there is a lack of consistent and reliable databases with emission coefficients on regional or national level across Europe. Data quality is an additional point of attention. Consistent and reliable data is essential to enable a comparison of improvement measures. A European database or national databases with a consistent (European) methodology/approach could be a way forward. But effective strategies to ensure the consistency, quality, and update of information etc. still remain a big challenge.

Finally, the analyses point out that carbon footprint calculations can be time consuming and skill-intensive. Coupling with existing tools (especially Bill of Materials (BoM), Bill of Quantities (BoQ), BIM, REVIT to obtain material quantities) and further optimizing this interaction has the most potential to reduce the skills and efforts needed.

→ Indicator options

Table 27: 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 | | | |
| B1b. Embodied energy use and GHG emissions | | | | | | | |
| Total primary energy consumption | kWh/year; normalised per m² 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 |
| Embodied carbon | tCO₂eq or normalized kgCO₂eq/m² floor] | A1-3 Production A4-5 Construction <u>Optional:</u> B1-B5 Use <ul style="list-style-type: none">- 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> ECO2 (Skanska Sweden), Klimagassregnskap (Norway), LCA-tools <u>Databases:</u> Inventory of Carbon & Energy (ICE) database ¹⁰³ ; Ecoinvent | Large variety in assumptions for life span, life cycle stages and scope | FS |

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

¹⁰³ Circular Ecology Ltd (2015) *Embodied energy and carbon - The ICE database*, [online] available at: www.circularecology.com/embodied-energy-and-carbon-footprint-database.html [Accessed 20/5/2016]

4.2. RESOURCE EFFICIENT MATERIAL LIFE CYCLES (MACRO-OBJECTIVE B2)

The scope of macro-objective B2 is quite broad and covers the following aspects: lean design, circular flows, material utility and the reduction of environmental impacts.

The macro-objective B2 field studies consist of the following clusters of buildings, each with a specific focus, which have been investigated by the JRC, VITO and ALTO Ingenierie:

- ALTO offices: new-build and renovation (France and Luxembourg). Construction and demolition (C&D) waste, design for deconstruction and disassembly, environmental impact assessment;
- ALTO residential: MacDonald masterplan (France). C&D waste, design for deconstruction and disassembly, environmental impact assessment;
- IRCOW project: C&D waste, design for deconstruction and disassembly;
- Ghandi/Hoogbouwplein: Design for adaptability, deconstruction and disassembly.

In addition, the Skanska and Eco-life study provide additional information, in particular with regards to the aspect “environmental impact”, although it is not the main focus of these field studies.

Furthermore, three cross-check studies have been considered in the analysis:

- Building permitting requirements for the assessment of the environmental performance of new-build residential and office buildings (The Netherlands);
- Construction & Demolition waste management requirements in Flanders, Belgium;
- Tracimat: a C&D waste management organization in Flanders (Belgium).

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

The field studies that focus on the aspect “lean design” are analysed by the JRC. The findings of this analysis are included in their synthesis report and are not covered in this document.

4.2.1. CIRCULAR FLOWS

→ Improvement options

Improvement options identified relate to:

- The *minimisation of waste* along the supply chain. This includes the diversion from landfill of C&D waste by recycling, reusing or energy recovering;
- The reuse of structural elements (or other hot spot building elements) *within a new building*.
- The substitution of virgin materials by *recycled or secondary/by-product materials*.

The IRCOW study focussed specifically on the recovery of demolition waste. Concerning the recovery rate of demolition waste, the Waste Framework Directive (2008/98/EC)¹⁰⁴ puts forward a value of minimum 70% (by weight) as a performance target.

In the certified office projects of ALTO, performance targets were put forward for construction waste diverted from landfill, ranging from 50% by weight (DGNB) to 75% (LEED) and 80% (BREEAM and HQE). While there were different performance targets identified in the field studies for construction waste and demolition waste, it should be noted that this distinction is not always made. For instance, in case of projects with demolition work included, certification schemes put forward other performance targets without distinguishing between C&D waste.

With regards to the reuse of building components, performance targets of 80% by volume were put forward for the in-situ reuse of existing structure or façade elements in the ALTO office renovation projects.

Another improvement option relates to the recycled content of building products. In case of the LEED certification scheme, credits are gained when materials are used that incorporate at least 10% or 20% recycled content. Furthermore, points are awarded when regional materials are used and as a result, transport is reduced. For instance, *the LEED certified office project of ALTO* aimed at achieving 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). In case of the *IRCOW project*, materials from demolition work are applied in high-grade products (e.g. reuse or high-grade recovery). No explicit quantitative performance targets were put forward, rather the performance requirements were defined qualitatively: the building products with recycled content have to comply with technical, environmental and durability standards and the maximum amount of recycled content is derived from this requirement. As a result, this differs from building product to building product and the application of the building component.

→ Tools, methodologies and standards

Building materials are diverted from landfill with the aim to recycle, reuse or recover the building materials. Therefore, the quality of the recovered materials is crucial. This quality, which is 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. Selective demolition can be preceded by a inventory of the planned demolition, in which all the building materials present in the building are mapped. Concerning demolition work, Belgium has specific federal and regional (Flanders) regulation related to material inventories and mandatory sorting of C&D waste. An asbestos inventory is compulsory for all activities (including demolition and refurbishment) in which employees are being exposed to asbestos during their work. So an asbestos inventory prior to demolition/refurbishment is compulsory for every type of building, if the demolition work is performed by a professional company (KB 16/03/2006)¹⁰⁵.

¹⁰⁴ article 11.2 states 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*".

¹⁰⁵ KB 16/03/2006 regarding the protection of employees against the risks of exposure to asbestos

A material inventory prior to demolition is compulsory for buildings of more than 1.000 m³ with a (partial) non-residential function (*VLAREMA 1/06/2012, art. 4.3.3*)¹⁰⁶. This is not compulsory in the case of refurbishments and renovations. The inventory must include a summary of the waste materials that will be set free during demolition/dismantling with data such as estimated quantity, description of the manner in which the waste materials (as described in *Vlarema art. 4.3.2*) will be selectively collected, stored and transported etc.

If no selective demolition was conducted, mixed material fractions might have to be sorted out, either manually (according to the European Standard EN 933-11) or by using advanced sorting techniques to obtain high-quality material fractions. Both methodologies were applied in the IRCOW study.

With regards to the recycled content of building products, the relevant technical, environmental and durability standards that apply depend on the type of building product.

→ Data requirements

For the material recovery ratio of demolition work, the processing certificates of the involved recycling plants or landfills are necessary. However, these do not always give enough information and don't allow to differentiate between different recycling practices (details can differ between different countries).

The fraction of recycled material in a new product requires the product recipe and can only be controlled in the beginning of the production process. The determination of the amount of contaminants in a material fraction is often a time-consuming manual work. Currently, other less time-consuming techniques are being developed.

→ Processes and actors

Table 28: Processes and actors – circular flows

| Methodology | Stage | Lead actor | Supporting actor |
|-------------------------------------|--|--|---|
| Inventory of building materials | End-of-Life (Demolition) | Third party who composes the inventory | Architect |
| Selective demolition | End-of-Life (Demolition) | Contractor | Architect |
| Sorting of waste | End-of-Life (Demolition) | Waste platform | - |
| Minimise waste disposal to landfill | Construction End-of-Life (Demolition) | Waste contractor, Waste platform | Architect, manufacturer |
| Recycled content | Production | Manufacturer | Waste platform, recycling facilities |

¹⁰⁶ *Vlaams reglement betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen*

A distinction can be made between building projects with demolition included and “regular” building projects without demolition.

The waste contractor is the lead party for selective demolitions in demolition projects, as the quality of the sorted waste streams depends greatly on the proper execution of the contractor. The architect has a supporting role, as he defines the technical specification of the selective demolition and performs the quality control.

Therefore, the inventory of building materials, which have to be composed by a third party before the demolition, can be very useful.

In regular building projects, as evidenced in the ALTO and Skanska projects, the waste quantities have to be derived from invoices of the waste contractors and waste platforms. In practice, it can be a challenge to obtain correct data of waste streams to landfill, recycling facilities etc. The waste contractor is the key actor. Supporting actors are the waste platforms, who provide the data; manufacturers, who recollect recycled or reused fractions; the architect, who designs the building and selects the construction materials.

Regarding recycled content, the amount of recycled materials in a product can be documented in the beginning of the production process, when all resources are added. The determination of the amount of recycled materials will be much more difficult after the production process.

→ **Inventory of lessons learned**

Recovery ratios can be expressed by weight or by volume. A mass-based indicator favours high-density waste streams. This means that waste streams with a very low density will be insignificant to reach the recovery ratio target. High-density waste streams (e.g. stony fraction) are currently recovered more than low-density waste streams (e.g. insulation materials, plastics). Lower recovery rates are obtained if the results are reported on a volume base.

The difficulty to reach recovery ratio targets depends on the country context. In fact, the field studies analysed indicate that conditions for C&D waste management can vary significantly among Member States. For instance, the IRCOW field study indicated that the average C&D waste recovery rate of building projects in Flanders of 95% by weight is among the highest in Europe. A high average recovery rate was also reported in France, in the ALTO office projects. A number of European countries however do not easily reach the 2008/98/EC recovery objective of 70% by weight. This is due to the construction culture, policy regulation or other context factors.

The nature of the project can also influence the recovery ratio. For instance in Flanders, recycling rates can be lower for smaller demolition work or demolition work with space limitations (for instance to stock the needed containers). 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.

Additionally, recovery ratios do not provide information about the type of recovery (reuse, recycling, energy recovery). Construction waste is easier to recover/recycle/reuse than demolition waste (e.g. bricks). Construction waste is less mixed than demolition waste because pure fractions can be obtained during construction. Furthermore, recovery ratios don't necessarily reflect the quality of the produced material streams and their recovery potential (e.g. separate recycling of the glass fraction vs. including the glass in the mixed stony fraction). In order to achieve high-grade recycled material, the amount of unwanted constituents in material streams needs to be limited. This can be achieved by a selective demolition process or by a sorting process after demolition.

The IRCOW field study analysis compared the practice of selective demolition with two business-as-usual case studies in Flanders. Emerging findings include:

- Lack of financial incentives are an important barrier for selective demolition (for instance, as it is more expensive to dispose gypsum, gypsum might be disposed together with AAC as it is not easily distinguished). In addition, Flanders has a landfill ban for recyclable C&D waste fractions;
- Small-scale demolition work or the lack of space can hamper selective demolition processes (e.g. the amount of container that can be placed);
- The selective disposal of non-recyclable hazardous waste is crucial for a viable circular economy. Purer waste streams with a low environmental risk clearly have a greater upcycling potential. Non-recyclable hazardous waste could be excluded from the recovery ratios. The Waste Framework Directive (2008/98/EC) also excludes hazardous waste;
- A selective demolition can differ from a non-selective demolition in several aspects (e.g. energy use of used equipment, the use of water in dust measures). The impact of an increased selectivity in demolition practices on these aspects is currently being investigated in LCA studies for the H2020 project HISER¹⁰⁷;
- Based on the processing certificates, a distinction cannot always be made between the type of recovery (reuse, recycling, energy recovery), because these certificates do not give information on the final recycling application. To respond to this, a supply chain tracking system (TRACIMAT) is currently being developed in Flanders, aiming to give a quality assurance to the recycling plants¹⁰⁸. Tracimat will issue a "certificate of selective demolition" for C&D waste that has been selectively collected and subsequently gone through a tracing system. Tracimat currently aims at a quality improvement of the stony fraction, by a selective removal of hazardous materials (e.g. asbestos) and low-strength materials (e.g. gypsum). The system is voluntary, but there is a financial incentive through a price differentiation in the gate fees of the recycling plants (low risk = lower gate fee).

It should be taken into account that Belgium has specific federal and regional (Flanders) regulation related to material inventories and mandatory sorting of C&D waste concerning demolition work. The regulatory context in Flanders can be seen as relatively favourable regarding selective demolition when compared to other regions in Europe.

A number of certification schemes specifically focus on rewarding the reuse of whole buildings, or major elements such as structures and foundations. This supposes evaluation of the extent to which a whole building's energy performance can be improved, but the reuse of hotspot elements within the building envelope could be supported.

Finally, the amount of recycled material in a new product as an indicator certainly has its merits. However, recycled content does not provide information on the quality of the end-product (durability) or the efficiency/quality of the recycling process (for instance, if the end-product was the result of "upcycling" or "downcycling"; a recycled product that would be recycled anyway versus a recycled product that would normally be disposed). As a result, this has to be completed with data on the quality and performance of the developed products (as was done in the IRCOW

¹⁰⁷ HISER, 2015, *Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste*, available at: www.hiserproject.eu [1/8/2016]

¹⁰⁸ HISER, 2015, *TRACIMAT – Tracing Construction and Demolition Waste Materials*, available at: <http://www.hiserproject.eu/index.php/news/80-news/116-tracimat-tracing-construction-and-demolition-waste-materials> [1/8/2016]

project) since the product has to be usable in the relevant conditions. The impact on sustainability of a replacement with recyclable materials depends on several factors (e.g. primary material that is replaced, type of recycled material, transport distances). To include these factors, LCA studies are necessary.

→ Indicator options

Table 29: Long list of macro-objectives 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 | | | |
| 2.4 Construction and demolition waste minimisation | | | | | | | |
| Reuse or renovation of buildings/elements | % (mass) | B5: Refurbishment C1-4: End of Life | Concept design Developed and technical design Construction Refurbishment | Building, elements or components | - | - | AR CC |
| % of structure reused | % (volume) | B5: Refurbishment C1-4: End of Life | | Superstructure Substructure | - | - | FS |
| % of façade reused | % (surface) % (mass) | B5: Refurbishment C1-4: End of Life | | Façade and envelope elements | - | - | FS |
| Waste arising during construction and/or demolition | m³ or m³ normalized per 100 m² floor area or m³ normalized per project cost | A4-5: Construction | Developed and technical design Construction | Excluding waste from earthworks/excavations and backfilling | Protocols developed by sectoral organisations, industry and Member States | - | CC AR |
| | | C1-C4: End of Life | | | | - | CC AR |
| | tons or tons normalized per 100 m² floor area or tons normalized per project cost | A4-5: Construction | | | | - | CC AR |
| | | C1-C4: End of Life | | | | - | CC AR |
| Material recovery ratio / Proportion of waste diverted from landfill | % diversion rate | C1-C4: End of Life | Technical design Demolition | Whole building and infrastructure (excluding excavated soil). Recovery= reuse, recycling, energy recovery. | Data: Bill of quantities or demolition inventory (design); processing certificates or invoices (demolition) | - | FS AR |

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

Table 30: Long list of macro-objective 2 supporting 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 | | | |
| 2.4 Construction and demolition waste minimisation | | | | | | | |
| Amount of contaminants recovered fractions | % (mass) | 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)

4.2.2. MATERIAL UTILITY

→ Improvement options

The aspect “material utility” of macro-objective B2, concerns the following improvement options:

- The *future adaptation potential* of structures, e.g. change of function, change of client specifications; change of performance requirements;
- The *ease of dismantling/separation* of hot spot building elements for reuse or recycling.

In the ALTO office projects, this is addressed mainly by the HQE and DGNB certification schemes.

HQE requires a design study, in which aspects related to future adaptability are highlighted. The study involves the specification of the building life span (where 10 years is defined as “short” and 100 years as “long”) and the life span of its building components. However, requirements and guidelines regarding the content of this study leave room for interpretation and as such, quality can vary significantly depending on the project and the company performing the study.

DGNB stipulates specific requirements for disassembly or adaptability and grants an overall rating, based on the level of compliance for each of these requirements. This category scoring is identified as state-of-the-art regarding material utility. Requirements relate to design measures, such as:

- Indoor clearance height is greater than 2.75 m;
- Non-bearing, room separating elements can be added to, converted, or removed without too much effort and with building operation continuing as normal (minimal impact on operation);
- Non-bearing, room separating elements can be dismantled, and there is a possibility of temporarily storing unnecessary elements;
- Power and media conduits run through easily accessible supply shafts, cable ducts, or false floors and/or the lines are visible;
- Less than 80 % of the capacity of the supply shafts and ductwork for power and media conduits is utilized;
- Waste water removal/supply system’s distribution and connections are designed in such a way that they could be modified for other types of use.

Furthermore, the scheme puts forward a space efficiency factor ($Seff = \text{Usable floor area} / \text{Gross floor area}$) to determine the efficient use of the floor area. In order to achieve the maximum credits, a space efficiency factor of at least 0.75 must be obtained. Of course, legal requirements for the size of work areas etc. have to be fulfilled at all times.

In the Ghandi and Hoogbouwplein projects, no quantitative performance targets were put forward. Instead, a qualitative approach was used and design guidelines were formulated on different building levels: building component, building and district. These design recommendations included, among others:

- Determine the frequency of adaptation for each building element based on the intentions of the current (and hypothetical future) building client(s);
- Develop adaptable, reversible and reusable solutions for building elements with a high expected frequency of adaptation;
- Create building elements designed for future adaptability, using available building products with standardised connections and assembly techniques, in order to allow for selective demolition and future reuse;

- Provide an internal layout of the building that allows multiple uses by: applying multi-purpose spaces; strategic clustering/subdivision of technical services and circulation facilities; adaptable and multi-purpose building structure. (Paduart et al., 2013)

→ Tools, methodologies and standards

From a standardisation perspective, EN 15643-3/EN 16309 provides some limited pointers as to measures to increase adaptability. ISO 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17, initiated by proposals from the Canadian Standards Association (CSA), and will provide architects, planners and building owners a set of design principles and quantifiable metrics to design and assess adaptable buildings and demountable building systems

In the Ghandi/Hoogbouwplein field study, an assessment framework for Design for Change has been developed and applied. The framework is publically available¹⁰⁹. The assessment framework 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 three characteristics per level: i.e. the interfaces between components, the characteristics of those (sub) components and their composition

Once a set of design alternatives is selected, the environmental and financial characteristics of each alternative are quantified by combining LCA and LCC.

→ Data requirements

Data requirements to assess the future adaptability of the building and ease of dismantling of building components can be obtained from the architectural drawings (both design drawings and technical drawings), as this involves data on building geometry.

Additional information on building component level can be obtained from the technical specifications or product certifications, for instance Environmental Product Declarations.

When the determination of life spans of buildings and building components are required, design assumptions might be needed, based on databases with building product life spans.

¹⁰⁹ <http://www.ovam.be/veranderingsgerichtbouwen>

→ **Processes and actors***Table 31: Processes and actors – Material utility*

| Improvement option/ Methodology | Stage | Lead actor | Supporting actor |
|--|---|--------------------------------|-----------------------------|
| Increase the future adaptation potential of the building | Concept design | Architect, structural engineer | Building client |
| Increase the ease of dismantling/separation of building components | Developed and technical design; Construction | Architect | Contractor, manufacturer |

Increasing the future adaptation potential of the building has to be addressed early in the design process. The architect and structural engineer hence play a key role. The design recommendations and guidelines developed in the Ghandi/Hoogbouwplein field study anticipate on this fact. The building client has a supporting role, as his requirements are decisive in the final design.

The architect plays also a key role in increasing the dismantling and separation potential of building elements as he specifies the building materials and the construction methods in the technical design and during construction. The contractor and product manufacturers have a supporting role, as they propose the actual building materials to be applied in the project.

Surveys of demolition contractors indicate that a combination of pre-demolition building inventory information (archived from the design stage) with a greater consideration at design and construction stage of the building's end of life (ease of dismantling/separability of building elements are cited) should be primary considerations for design teams and clients.

→ **Inventory of lessons learned**

Whilst the potential for future adaptability of buildings is highlighted in literature as being an important consideration, there are no mature indicators currently in use. EN 15643-3/EN 16309 provide some limited pointers as to measures to increase adaptability. ISO 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17, initiated by proposals from Canada.

A composite score can be derived, for instance based on a checklist as included in the DGNB-scheme, which could form the basis for an indicator for office buildings. More work is needed to fully incorporate the concept of change of function from office to residential and vice versa. Currently ongoing work to develop design tools (e.g. the H2020 project BAMB: Buildings as Material Banks¹¹⁰) may serve to further inform indicator development.

Design life and/or service life for a building, elements and components are considered in a number of certification schemes and there is a strong link with material utility and MO B6. For instance, in case of HQE, a building life estimation is required (e.g. ranges from 10 to 100 years). Life span of building components has to be related to this building life estimation. One of the objectives of this approach is to list which elements will have to be replaced during the estimated life span of the

¹¹⁰ BAMB, 2015, *Buildings as material banks*, accessible at: www.bamb2020.eu/ [1/8/2016]

building. However, as these concern design assumptions, this rarely corresponds with reality. For instance, buildings are commonly renovated before the default declared duration of 50 years.

Consideration of the disassembly potential of a building is a new and difficult concept for design teams and clients. There are no mature indicators to measure disassembly potential, but it is a concept that is already practiced for some building types e.g. light industrial, 'circular contracts' in the Netherlands. As already noted for adaptability, ISO 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17, initiated by proposals from Canada. This is also intended to address disassembly.

The state of the art is a category scoring for ease of disassembly, scope of disassembly and viability of disassembly (DGNB). This could form the basis for an indicator, with the scope defined in order to focus attention on hotspot building elements.

→ Indicator options

Table 32: 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 | | | |
| Design for flexibility and adaptability | | | | | | | |
| Adaptability score | Weighted sum of 7-15 aspects | B1-7: Use <ul style="list-style-type: none">- Repair- Replacement- Refurbishment | Concept design Developed and technical design | Building arrangement, floor layouts, servicing strategies | With reference to assessment scheme methodologies | - | AR CC |
| Design for deconstruction and disassembly | | | | | | | |
| Ease and scope of disassembly | Category score | C1-4: End of Life | Concept design Developed and technical design Construction | Building, elements or components | With reference to assessment scheme methodologies | | AR CC |

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

4.2.3. ENVIRONMENTAL IMPACT

→ Improvement options

Identified improvement options concern the material selection of building materials with low environmental impact, supported by an assessment of the environmental impact based on Life Cycle Assessment (LCA) of buildings or building elements.

In the majority of the field studies, no quantitative targets are defined. Rather, LCA is used to compare different design options for building components.

In the ALTO office projects, the criteria of HQE and BREEAM regarding the environmental impact of building materials were applied. Performance targets were put forward on building component level. The requirement was limited to the fact that if an environmental assessment was conducted on the building components of one or more product groups (e.g. structural elements).

In the ECO-LIFE field study, the objective was to use building materials with rating of 3b/3c or better according to the NIBE classification system¹¹¹, when financially reasonable (pragmatic approach).

→ Tools, methodologies and standards

The main methodology applied is Life Cycle Assessment (LCA) according to LCA standards such as ISO 14040-14043, EN 15978, EN 15804 and ISO 21930.

BREEAM and HQE each have their own tool to conduct LCAs. BREEAM uses its MAT 1 calculator, under the framework of the Green Guide¹¹² 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 and acidification. The tool is based on the Environmental Profiles PCR¹¹³, which defines the life cycle stages, impact categories and data preparation process, both for the BRE (who carry out the LCA/operate the scheme) and product/building element manufacturers (the ratings are derived from average building element performances)

HQE uses the national LCA-tool of France, ELODIE¹¹⁴, developed by the French research institute CSTB, further supported by the French EPD scheme – the FDES (Environmental and Health Declaration)¹¹⁵.

¹¹¹ NIBE, 2011, *Nederlands Instituut voor Bouwbiologie en Ecologie*. Available at: <http://www.nibe.org/nl> [1/8/2016]

¹¹² BRE, 2016, *Green guide to specification*, available at: <https://www.bre.co.uk/greenguide/podpage.jsp?id=2126> [1/8/2016]

¹¹³ BRE, 2016, *Environmental Profiles*, available at : http://www.bre.co.uk/Environmental_Profiles.html ([1/8/2016]

¹¹⁴ CSTB, 2016, *ELODIE*, available at: <http://editions.cstb.fr/Products/Elodie> [1/8/2016]

¹¹⁵ <http://www.inies.fr/accueil/>

In the Ghandi project, the calculation of the initial and life cycle environmental impact (IE and LE, respectively) is based on the Belgian assessment method MMG¹¹⁶, in line with EN15978¹¹⁷ and ILCD Handbook¹¹⁸. Within the MMG method, environmental impacts are expressed in individual impact indicators (expressed in kg impact-equivalent/m² net floor area), but also as an aggregated indicator, based on external environmental costing¹¹⁹.

The method applied in the Ghandi field study, has some similarities compared to the national assessment method applied in The Netherlands: Assessment Method Environmental Performance Constructions and Civil Engineering (GWV) Works¹²⁰. In the Netherlands, building permitting requires the assessment of the environmental performance of new-build residential and office buildings according to this method. It is based on the European Assessment Method for environmental declarations of construction products (EN 15804) and is linked to a National Environmental Database (Nederlandse Materiaal Database (NMD)). The result of the calculation is an environmental profile, which covers seven environmental impact categories (according to EN 15804), complemented with four additional toxicity categories. The Assessment Method aggregates these seven impacts into two key environmental indicators (emissions and raw materials) and a single-point score. The weighing is done using a shadow pricing method.

By nature, LCA is quite complex and thus requires advanced skills and dedicated effort. To improve the use of LCA in building projects, ENSLIC explored simplified LCA-tools, as already described in section 0.0.0.2 (macro-objective B1).

In ECO-LIFE, even more simplified tools were used to support building designers, such as the Dutch NIBE handbooks with environmental classifications of buildings or the Flemish VIBE information sheets for selection of building materials. Labeling systems provide comparable support in material selection during the concept or technical design. These can be product specific for instance PEFC¹²¹ or FSC¹²² certification in case of timber.

→ Data requirements

Data reliability, availability and quality is a key issue with regards to using LCA in practice. Issues related to it are already covered in the discussion of the data requirements for macro-objective B1 – embodied carbon (see section 0.0.0.2).

¹¹⁶ 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 on http://www.ovam.be/sites/default/files/FILE1368696514672Environmental_profile_buildig_elements_LR.pdf

¹¹⁷ CEN (2011), EN 15978 Sustainability assessment of construction works – assessment of environmental performance of buildings – calculation method

¹¹⁸ 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.

¹¹⁹ 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>

¹²⁰ <http://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012/hfd5/afd5-2/art5-9>

¹²¹ <http://www.pefc.org>

¹²² <https://ic.fsc.org/en/certification>

→ **Processes and actors***Table 33: Processes and actors – Environmental impact*

| Methodology | Stage | Lead actor | Supporting actor |
|---|---|--------------------------|----------------------------|
| Classification and certification systems, labels | Concept design | Architect | Manufacturer |
| LCA of different options for selected building components | Concept design Developed and Technical design | Environmental consultant | Architect, building client |
| LCA of buildings | Developed and Technical design, Construction | Environmental consultant | Architect, building client |

In practice, LCA requires an experienced practitioner to conduct the calculations. Simplified LCA-tools are used in the concept design stage. A further distinction can be made between LCA of buildings and LCA of building components.

At concept design stage, classification systems and labels provide a more accessible source of information in the aim to select building materials with a low environmental impact.

→ **Inventory of lessons learned**

In the field studies analysed, the environmental impact of buildings is assessed based on LCA methodologies. In practice, LCA is commonly applied on building component level to compare different design or construction options. LCA on building level is less common, although certification schemes are evolving towards this approach in recent versions.

Simplified LCA-tools such as BREEAM's Green Guide and HQE's Elodie, but also certification (e.g. FSC-labels) and classification systems (e.g. NIBE) are reported to be user-friendly and more easy to use in early design stages. However, assumptions in the tool or methodology (for instance regarding life cycle stages and environmental impact considered, or databases used) are not always transparent or clear (e.g. Green Guide which has a "black-box" approach).

A key discussion point is whether to use a set of individual (impact) indicators (for instance, the seven impact categories defined by CEN TC350), or use an aggregated/weighted (set of) indicator(s).

The first option has the advantage that no extra normalisation and weighting steps are required. Accordingly, the chosen indicators are very close to the environmental mechanism for each impact category. However this option makes it difficult to compare two or more building or building element alternatives. In general it rarely happens that one alternative is characterised by the lowest environmental impact for ALL impact categories. Hence, decision-making based on an (independent) set of individual life cycle impact indicators is not practical. This is true for designers, building clients, but also for policy actors. Option 1 is used for 'hot-spot analysis'.

The second option is either based on a single indicator covering ALL individual impact categories and/or a limited set of 'damage' indicators, by grouping individual impact categories together based on the type of potential damage (e.g. related to human health, ecosystems and resources). This is usually done by adding two steps after characterising impacts: (1) normalisation (e.g. based

on the impact of a European citizen in a reference year) and (2) weighting. Different types of weighting exist. A good overview is given by JRC IES¹²³. Although there is no consensus on a 'universally accepted weighting scheme' [note: there will never be, because it involves normative values], it does provide insight into the pros and cons for each approach. Using an aggregated indicator is a practical solution for comparisons and decision-making (based on comparisons), but is further away from the real environmental mechanism. Both options clearly have advantages and disadvantages. There is also an option in between, where you only take into account a (limited) set of most important impact indicators. The biggest issue here, is that it is only possible to know when impact categories are negligible, when all of them are actually calculated. However, as it is the same as assigning a weighting factor of 0 to some of the impact categories, this can also be interpreted as weighting.

Further elaborating on the impact categories, it should be taken into account that within the CEN/TC 350 standards, only a limited number of impact categories are covered. In some EU Member States the uptake of several additional indicators has already taken place:

- France: pollution of air and water (method: XP P 01-064/CN)
- Netherlands: human and ecotoxicity (method: CML) according to Dutch Decree
- Belgium: human toxicity (cancer and non-cancer), particulate matter, depletion of resources, ecotoxicity (soil and marine) and land use (soil quality and biodiversity) (method: in line with PEF & ILCD Handbook) according to Belgian Royal Decree (22th May 2014)

CEN/TC 350 has investigated the option to include additional environmental impact categories in the CEN standards EN15804 and EN15978: human toxicity, ecotoxicity, particulate matter, land use, biodiversity, water scarcity and ionising radiation.

It is also important to mention that the mandate M/350 given to CEN TC350 will be revised, in order to facilitate the convergence of the methodology used within the CEN standards and the PEF methodology. To anticipate on these developments, it is recommended to align the development of Core Indicators with the CEN TC350 and/or PEF activities.

¹²³ Huppers, G., van Oers, L., 2011, *Background Review of Existing Weighting Approaches in Life Cycle Impact Assessment*, JRC IES, available at: <http://eplca.jrc.ec.europa.eu/uploads/LCIA-review-of-weighting-methods.pdf> [1/8/2016]

→ Indicator options

Table 34: 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 | | | |
| 2.5 Environmental impact | | | | | | | |
| Individual environmental impact indicators | Depending on the environmental impact category | A1-3: Production A4-5: Construction B1-7: In-use C1-4: End of Life | Developed and technical design | Building or building elements or components | EN 15978 (building), EN 15804 (building elements); advanced LCA-tools such as GABI or SimaPro; simplified LCA-tools (e.g. ENSLIC) | CEN/TC 350 or PEF impact categories | FS |
| Aggregated or weighted (set of) environmental impact indicators | EUR | A1-3: Production A4-5: Construction B1-7: In-use C1-4: End of Life | Developed and technical design | Building elements or components | MMG-method (regional method in Flanders) | - | FS |
| | Rating or classification system | | Concept design; Developed and technical design | Building elements or components | NIBE classification; BREEAM's Green Guide rating; CSTB's ELODIE tool | - | FS |
| | single-point-score | | Developed and technical design | Building | Assessment Method Environmental Performance Constructions and Civil Engineering (national method in The Netherlands) | - | FS |

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

4.3. WATER USE (MACRO-OBJECTIVE B3)

Macro-objective B3 covers the efficient use of water resources. In addition, the identification of areas with long-term or projected water stress and the impact on water use strategies.

The macro-objective B3 field studies consist of two clusters of buildings, each with a specific focus, which have been investigated by VITO and ALTO Ingenierie:

- ALTO offices – new-build and renovation projects (France and Luxembourg): Operational water use;
- ALTO residential – MacDonald masterplan (France): Operational water use.

4.3.1. IMPROVEMENT OPTIONS

The following improvement options were identified:

- Reduce the consumption of potable water during the building's use stage (operational water consumption);
- Reduce the water demand by applying water recycling strategies such as rainwater harvesting or greywater reuse;
- Monitor water consumption by installing sub-meters or connect it to the Building Management System (BMS);
- Reduce water footprint of the construction site.

The certification schemes define specific performance targets and benchmark values for the operational water consumption. A clear distinction can be made between the approach in office and residential projects.

In the ALTO office projects, the performance targets put forward by HQE, BREEAM and LEED are defined on building level. They are expressed in terms of the building's occupants in L/person or m³/person, either on daily or yearly basis. Threshold values differ, depending on the certification scheme. In addition, relative targets are defined by HQE and LEED: % of reduction compared to a baseline performance.

The approach of DGNB is different. Although performance targets are defined on building level as well, it puts forward a water use value (in m³/year), which covers both potable water and wastewater use.

Performance targets for each certification scheme can be summarized as follows:

- HQE compares the water consumption of the building to the water consumption of a reference building. Compliance requires 100% of the reference consumption, maximum performance is achieved for 50% of the reference consumption. The reference consumption is calculated using the same building parameters (number of sanitary appliances, occupants) but with default values for the WCs, urinals, taps and showers;
- The approach of LEED is similar to the one of HQE. Compliance requires 30% of water reduction compared to a calculated reference consumption; maximum performance is achieved when 40% reduction is achieved. The reference consumption is calculated using default flow rates for WCs, urinals, taps and showers, however the threshold for these appliances defined by LEED seem to be more stringent and therefore harder to achieve than HQE and the other certification schemes, based on the experience of the ALTO field studies. For instance, in case of lavatory taps, a flow rate of 2 L/minute (LEED) is required compared to 10 L/minute (HQE) and 9 L/minute (DGNB);

- BREEAM requires a water consumption lower than 5,5 m³ per person per year. Maximum credits can be achieved when consumption is lower than 1,5 m³/person per year.
- DGNB puts forward three performance targets: a limit value, reference value (66% of the limit value) and target value (33% of the limit value). The limit value differs for buildings with or without showers and has to be calculated according to a formula provided in the guidelines. The limit value is required to obtain credits, maximum performance requires the achievement of the target value.

In the ALTO residential masterplan, there are no performance targets defined on building or dwelling level. Residential certification schemes currently do not set targets based on actual consumption (metering data) but based on performance of the sanitary appliances (equipment details of manufacturers) instead. Targets are expressed in liter or volume per flush, per minute or per second and could differ depending on the type of appliance (toilet, bath, shower or water tap). In Boulevard MacDonald in particular, the French “ECAU” classification system¹²⁴ is in force:

- “E” corresponds with flow rate requirements
- “C” corresponds with ergonomic requirements
- “A” refers to the acoustic performance
- “U” refers to the durability of the equipment

As an illustration for class “E”: The flow rate requirements consist of five categories (E0 to E4), which correspond with the following values:

- 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)

With regards to the other improvement options, it is observed that they are not necessarily linked to quantified targets, rather requirements are defined which have to be complied or not.

Regarding water recycling strategies: Greywater recycling or rainwater reuse are not mandatory by HQE but in order to achieve the maximum credits in DGNB, BREEAM and LEED, it has to be proven that these systems are applied. Furthermore, the calculations of the design teams may additionally be required to provide the necessary input into the water calculation tools of the assessment scheme. In some cases the calculation methodology is detailed in the criterion guidance – for example in DGNB.

HQE does not explicitly require the application of water recycling strategies, but does award credits if a proportion of the water demand is covered by non-potable water sources, ranging from 10% to 25% to 50%.

Regarding the monitoring of water consumption through the installation of water meters and a Building Management System (BMS): In the office projects, all certification schemes require the installation of (sub)meters and this is also now required by French regulation for new buildings. A BMS is not mandatory, but credits can be obtained in HQE and BREEAM when water meters are connected to the system, programmed to verify the water consumption and set to sound an alarm in case of excessive use (e.g. leak detection).

¹²⁴ <http://evaluation.cstb.fr/classement/ecau>

4.3.2. TOOLS, METHODOLOGIES AND STANDARDS

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 manufacturer's data for sanitary fittings. Outdoor water usage tends to be handled as a separate calculation. Some certification schemes distinguish between uses for which potable water is required and those for which 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 rainwater, greywater.

In the ALTO office projects, each certification scheme seems to use their own developed water calculation tool to assess the operational water consumption. Calculations are based on technical data and occupation. Data input, default and threshold values, assumptions and scope vary, depending on the certification scheme. - The scope is limited to operational water consumption, although water consumption in the construction stage is (optionally) addressed in certain certification schemes.

HQE allows for the calculation of water consumption using either a spreadsheet developed by HQE's certification body CERTIVEA or the water consumption module of ELODIE.

Necessary input parameters are: characteristics of the sanitary appliances (number of appliances, flow rate and for certain appliances such as showers, the intensity of use) and characteristics of the users (number of permanent occupants, number of visitors, ratio male/female).

Water use included in the calculation are: toilets, urinals, taps (lavatories and kitchen sinks) and showers. Water used by technical installations are reported separately (for instance, non-potable water (sprinkler)): m^3/year or m^3/m^2 per year. Process water such as laboratory equipment, equipment linked to the tenant or specific program of the building is not considered in the methodology (e.g. washing machine, food preparation). Reduction of water demand through rainwater harvesting or greywater reuse is not integrated in the water consumption calculation of HQE, in contrast to BREEAM, LEED, DGNB.

LEED uses its own spreadsheet as well. The approach is similar to the HQE water tools. The tool is transparent and well-explained (e.g. compared to BREEAM). Calculations are based on estimated occupant usage (similar to HQE). Following sanitary appliances are considered: water closets, urinals, lavatory taps, showers and kitchen sink taps (these are the same as for HQE).

BREEAM has developed its own tool too. However, the BREEAM Water Calculator tool is a “black-box” and the calculation methodology behind it is not totally clear. Input parameters required are limited: only flow rates and flush volumes of the sanitary appliances have to be inserted. Water use in the calculations includes: toilets, urinals, taps (only lavatories) and showers. However, kitchen taps, cleaners' sinks and external taps are not included which is different compared to HQE.

The calculated water consumption figure is influenced by greywater reuse and rainwater harvesting, but it is difficult to assess the improvement that can be expected when applying these strategies up-front due to the “black-box” nature of the tool.

The methodology used by DGNB is the most comprehensive among the four certification schemes. It covers both drinking water demand and wastewater volume (see Figure 25). The water demand includes not only toilets, urinals, taps and showers but also cleaning and irrigation. Water demand reduction strategies such as rainwater harvesting and greywater reuse are considered in the calculation as well. As a result, more input parameters are required. The guidelines provide additional support in making the assumptions necessary for the calculations.

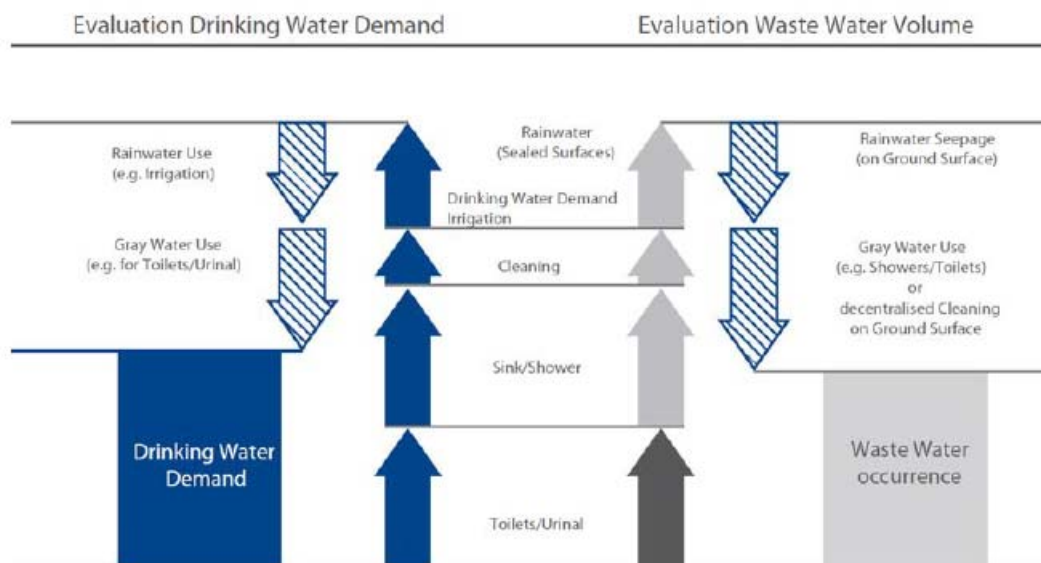


Figure 25: Scheme of the methodology applied in DGNB's water calculation (source: DGNB (2014))

In the ALTO residential masterplan, no specific water calculation tool was used as the methodology is more straightforward (i.e. on the level of the sanitary appliances). The ECAU classification was already explained in previous section.

Regarding rainwater harvesting and greywater reuse, LEED and HQE leave it up to the technical designer to calculate the amount of rainwater and greywater with their own calculations.

In case of BREEAM, if rainwater collection or greywater recycling systems are specified for the purpose of meeting WC/urinal flushing demand, it is required to provide the following information in order to calculate the water demand:

- Annual rainfall for the site location (mm);
- Rainwater catchment area (m²);
- Roof type e.g. pitched roof, flat roof;
- Rainwater filter co-efficient and rainwater collection tank capacity;
- Percentage of tap and shower water collected and used for WC/urinal flushing;
- Percentage of building's WC/urinals using greywater to meet flushing demand.

In case of DGNB, the amount of rainwater and greywater used have to be specified by the technical designer. In addition, the quantity of rainwater diverted to sewers has to be calculated using the following parameters: annual rainfall at the location, sealed and green area surface and their yield coefficients according to the German standard DIN 1989 or local standards, quantity of rainwater used for irrigation or toilet flushing.

4.3.3. DATA REQUIREMENTS

Data requirements are already discussed in the section 4.3.2 "Tools, methodologies and standards".

Building information is derived from the technical drawings of either the architect or engineering firm. Information of the building users depend on design assumptions or data provided by the

building client. Technical information of the sanitary appliances such as flow rates and flush volumes rely on the technical data sheets provided by the manufacturer.

4.3.4. PROCESSES AND ACTORS

Table 35: Processes and actors – Water use

| Methodology | Stage | Lead actor | Supporting actor |
|---|--|-------------------------------|---|
| Selection of sanitary appliances | Concept design; Developed and technical design | Architect, technical engineer | Building client |
| | Construction | Architect, technical engineer | Contractor |
| Water demand reduction strategies e.g. rainwater harvesting | Concept design; Developed and technical design | Architect | Technical engineer |
| Monitoring operational water consumption | Developed and technical design; Construction | Technical engineer | Architect, building client |
| | In-use | Building manager | Occupant, building client, technical engineer, contractor |

Regarding the selection of the sanitary appliances, the architect and technical engineer have the leading role during the design stage. During construction, performance of sanitary equipment is verified by the architect and technical engineer, based on manufacturer's data (technical fact sheets) provided by the contractor.

4.3.5. INVENTORY OF LESSONS LEARNED

Compared to the other certification schemes, the DGNB method stands out for its holistic approach, in particular it includes the impact of demand reduction strategies, as well as other water uses such as cleaning. The methodology behind the calculations and the assumptions are clearly defined and well-documented in the accompanying guidelines. As a result, the water use values of different projects can be more easily compared to other water indicators. The methodology does seem to require more data input (for instance, additional data on wastewater volume) and thus requires more effort for the calculation. Another important asset of the DGNB method is its transparency. The tool is understandable for the design team and therefore very useful to steer improvement.

BREEAM's water tool is less transparent as it has a rather "black box" approach. For this reason, it is difficult to use the BREEAM tool to provide insight in design options and it is seen as less useful in decision-making.

The standard ambition levels of the certification criteria for the water consumption performance targets were not difficult to achieve, with the exception of the LEED thresholds for sanitary appliances.

The main difference between the ALTO office and residential projects is the fact that performance targets for water consumption are defined on the level of the building (normalized per person) in case of office projects and on the level of the sanitary appliances (as a target flow rate) in case of residential buildings.

Regarding water demand strategies, more in particular rainwater harvesting and greywater reuse, it is noted that regional or national regulation can have an important influence, both in positive and negative sense. For instance, in Luxembourg, rainwater harvesting is common practice and it has an important contribution to the net water consumption targets. The rainwater harvesting requirements were in fact more stringent as a result of local regulation compared with some of the certification schemes. On the other hand, greywater reuse was in some projects impossible due to legislation.

4.3.6. INDICATOR OPTIONS

Table 36: 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 | | | |
| 3. Operational water consumption | | | | | | | |
| total water consumption (during use stage) | Litres/person/day | B7: Operational water consumption | (Concept design) Technical design Construction | based on flow rate of sanitary appliances | with reference to: - assessment scheme calculation methodologies and - regulatory requirements and calculation methods | - | FS |
| | m ³ /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 |
| intensity of water consumption | normalised to reflect occupancy rate | B7: Operational water consumption | (Concept design) Technical design | See above | | - | FS |
| reduction of water consumption | % reduction compared to reference value | B7: Operational water consumption | (Concept design) Technical design Construction | | | - | FS |
| total water consumption (during construction) | Litres/person/day | A4-5: Construction | Construction | - | - | - | FS |

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

Table 37: Long list of macro-objective B3 supporting 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 | | | |
| B3Operational water consumption | | | | | | | |
| Flow rate of sanitary appliances | l/flush; l/minute (depending on appliance) | B7: Operational water consumption | Concept design Technical design Construction | Sanitary appliances (cisterns, urinals, washbasins, showers...) | | | FS |
| Proportion of rainwater reused | % | B7: Operational water consumption | Concept design Technical design | | - | - | FS |
| | m² | B7: Operational water consumption | Concept design Technical design | Surface area recovered for rainwater harvesting | - | - | FS |
| Proportion of greywater reused | yes/no | B7: Operational water consumption | Concept design Technical design | | | | FS |
| Installation of water metering | m³ | B7: Operational water consumption | In-use | | | | FS |

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

4.4. HEALTHY AND COMFORTABLE SPACES (MACRO-OBJECTIVE B4A)

Macro-objective B4a “Healty and comfortable spaces” focusses specifically on the 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, damp and mould have additionally been identified as significant health issues (biological hazards), and 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 avoidance of hazardous materials in the first place.

Summary of aspects covered:

- Exposure to hazardous substances – ventilation intake air;
- Exposure to hazardous substances – materials’ emissions;
- Exposure to hazardous substances – (de)construction of building components;
- Moisture and mould.

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;
- OFFICAIR: 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.

In addition, three cross-check studies are considered in the analysis. The first relates to the emission classification system in Finland, while the other two specifically address the aspect of moisture and mould:

- A study, conducted by the Finnish research institute VTT on reference values building survey linked to the M1 standard (Finland);
- National moisture and mould program in Finland;
- HITEA: Epidemiological study on dampness and moisture problems in residences (four EU countries).

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

4.4.1. EXPOSURE TO HAZARDOUS SUBSTANCES – VENTILATION INTAKE AIR

→ Improvement options

Concerning the exposure to hazardous substances resulting from the ventilation intake air, a distinction can be made between improvement options that target specifically hazardous substances as the result of the intake (of outdoor) air and improvement options that focus on the performance of the ventilation system.

Regarding the first point, in a number of field studies (especially the office projects), criteria are put forward to limit the intake of outdoor pollutants, either qualitatively by specifying requirements for the location and distance of air intake and exhaust openings or quantitatively by specifying filter class requirements based on outdoor and indoor air classes, in compliance with EN 779 (and ASHRAE 52.2 in case of LEED). The European standard EN 13779 serves as the main reference and the certification schemes BREEAM and LEED include specific requirements concerning these aspects.

However, the second point is emphasized more, as all the field studies highlight the importance of a general ventilation strategy with performance targets based on health or comfort criteria. Minimum ventilation flow rates are formulated. Local regulation or standards can apply but in general, reference is made to the European standards EN 13779 and EN 15251, as is the case in the four certification schemes (HQE, DGNB, LEED and BREEAM). While LEED allows to use these EN standards in European projects, the certification scheme also makes reference to the ASHRAE standard 62.1-2007, although it can have quite big differences in required ventilation flow rates¹²⁵.

EN 13779¹²⁶ specifies guidelines for the design of ventilation systems in non-residential buildings. EN 15251 specifies the indoor environmental parameters that relate to thermal comfort, indoor air quality, lighting and acoustics and that can have an impact on the energy performance of buildings.

A distinction can be made between residential and non-residential buildings. This results in other performance targets and approaches. EN 15251 covers both building types; EN 13779 only covers non-residential buildings but refers to CEN/TR 14788 for residential buildings.

In the case of the ALTO office projects, targets of 25 m³/h per person (HQE) and 36 m³/h per person (BREEAM) were put forward, which corresponds with 7 l/s per person and 10 l/s per person, respectively. Both certification schemes refer to Table 38 of EN 15251. In the case of LEED, an additional credit can be obtained when these minimum rates are increased with 30%, which in reality is a rather tough target to achieve.

Table 38: Basic required ventilation rates for diluting emissions (bio effluents) from people for different categories

| Category | Expected Percentage Dissatisfied | Airflow per person (l/s/pers) |
|----------|----------------------------------|-------------------------------|
| I | 15 | 10 |
| II | 20 | 7 |
| III | 30 | |
| IV | > 30 | < 4 |

However, it should be noticed that EN 15251 annex B describes several approaches to set performance targets for ventilation rates:

¹²⁵ Olesen, B., (2012) *Revision of EN 15251: Indoor Environmental Criteria*, Federation of European Heating, Ventilation and Air Conditioning (REHVA)

¹²⁶ EN 13779 (2007) *Ventilation of non-residential buildings – guidelines for ventilation systems and air-conditioning*

- A required ventilation rate composed from two components: ventilation for pollution from the occupants and ventilation for the pollution from the building and its systems. DGNB specifically refers to this approach;
- A required ventilation rate per person (i.e. occupants as the main source of pollution) or per square meter floor area (i.e. pollutions from material emissions). The standard still offers different possibilities: based on the addition of the values (this is similar to previous bullet), based on the highest value (maximum of the calculated value based on per person and the value based on per m² floor area) or a value between the highest value and the value based on addition. HQE and BREEAM follow this approach;
- A ventilation rate based on CO₂ levels. This option is especially relevant in case of demand control ventilation.

In case of a ventilation rate based on CO₂ levels, reference is made to EN 13779, which defines thresholds for the difference in CO₂ level between indoor and outdoor air, in parts per million (ppm) for four different indoor air classes (IDA-classes).

Table 39: CO₂-level in rooms

| Category | CO ₂ -level above level of outdoor air in ppm | |
|----------|--|---------------|
| | Typical range | Default range |
| IDA 1 | ≤ 400 | 350 |
| IDA 2 | 400 - 600 | 500 |
| IDA 3 | 600 - 1000 | 800 |
| IDA 4 | > 1000 | 1200 |

For residential buildings, the ventilation rate requirements depend mainly on three criteria:

- Exhaust of pollutants in wet rooms (bathroom, kitchen, toilets);
- General ventilation of all rooms in the dwelling;
- General ventilation of all rooms in the dwelling with fresh air criteria in the main room (bedrooms and living rooms).

The ventilation flows of the bedrooms and living rooms in the dwelling are expressed as:

- an air change per hour (ACH) for each room;
- required exhaust rates (bathroom, toilets, and kitchens);
- transfer air from the bedrooms and living rooms as the supply air to the wet rooms.

Table 40: Example of ventilation rates for the residences (source: EN 15251 Table B.5)

| Category | Air change rate | | Living room and bedrooms, mainly outdoor air flow | | Exhaust air flow, l/s | | |
|----------|---------------------|-----|---|--------------------|-----------------------|-----------|---------|
| | l/s, m ² | ACH | l/s, pers | l/s.m ² | Kitchen | Bathrooms | Toilets |
| I | 0.49 | 0.7 | 10 | 1.4 | 28 | 20 | 14 |
| II | 0.42 | 0.6 | 7 | 1.0 | 20 | 15 | 10 |
| III | 0.35 | 0.5 | 4 | 0.6 | 14 | 10 | 7 |

These performance targets all concern design values. Criteria related to the quality control of the performance of the ventilation system have been identified in the field studies for both office and residential buildings. These not only relate to post-completion verification but also to measures during the use stage. For instance, in the case of offices, LEED, DGNB and BREEAM award the installation of permanent monitoring systems to ensure that ventilation systems maintain design minimum requirements, with triggers to produce an alarm (or as DGNB formulates it: a “traffic-light” signal) to the Building Management System (BMS) or the building occupant in case the design values are exceeded. Furthermore, BREEAM and HQE provide additional credits when a demand-control ventilation strategy (based on CO₂-sensors) is installed (in particular for rooms with varying occupancy patterns, for instance in the case of HQE). In the case of residences, the ECO-life and Cleanair, lowenergy field studies touch upon the importance of an adequate maintenance of the ventilation system.

To conclude, the performance targets clearly highlight the fact that the ventilation strategy cannot be seen without taking into account the pollution of the outdoor air and pollution of the indoor air of the building as a result of material emissions.

→ Tools, methodologies and standards

The main reference standards regarding ventilation are the following:

- ALTO projects: EN 13779;
- HQE, DGNB and BREEAM: EN 15251;
- LEED: ASHRAE standard 62.1-2007.

In INSULatE, Officair, Renovair and Cleanair Lowenergy, in-situ active air flow measurements were performed using flow boxes or flow meters to determine the fresh air ventilation flow rates and to measure the airflow passing through a supply or exhaust air device. In order to compare the results with regulations and standards, the air flow rate should only consider “fresh air” inlet, excluding the fraction that recirculates. During testing, it occurred that several extraction or supply vents could not be tested due to their positioning in/behind furniture and wall flashings. In these cases, the flow rate was estimated based on the design flow rate and the other measured flow rates in the dwelling.

In Officair, a passive ventilation assessment using the perfluorocarbon tracer (PFT) technique was used in selected cases as an alternative for air flow measurements.

EN 13779 serves as the main guidance document to assess the airtightness of the ventilation system for non-residential buildings. The standard cross-references to other standards for testing specifications and for estimating the leakage rates and its influence of air flows and energy consumption.

The airtightness or air leakage of buildings was tested using a building pressurization test, following the methodology proposed in the EN 13829:2000 Standard - Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (replaced by EN ISO 9972:2015).

→ **Data requirements**

The data required to assess this aspect of macro-objective B4a, relates mostly to project-specific data: building information (such as volume and surface of the spaces), occupancy and use, and ventilation system characteristics.

→ **Processes and actors**

Table 41: Processes and actors – ventilation strategy

| Methodology | Project stage | Lead actor | Supporting actor |
|--|--|---|--|
| Design of the ventilation system | Concept design, developed and technical design, construction | Technical engineers, energy expert, architect | Architect |
| Air flow measurements | Construction; handover and close-out | Technical engineers, energy expert | Architect, contractor |
| | In-use | Building manager | Technical engineer, contractor |
| Airtightness tests of the building and/or ventilation system | Construction; handover and close-out | Third party conducting the performance tests | Contractor, architect, technical engineers |

In practice, the technical engineers are the mainly responsible for the design of the ventilation system and the follow-up during construction. In the ALTO cases, this follow-up typically includes: verification of the technical specifications of the components of the ventilation system and the calculation notes of contractors during construction; verification of the data from the Building Management System (BMS) if in-place and verification of the flow rates during commissioning; and finally updating the input of the energy calculations. Feedback from the completed ALTO office projects indicated that results of flow rate measurements can be difficult to acquire from the contractors.

The supporting actors are the actors who have to provide the information necessary for the assessment or have to take corrective actions if needed.

The airtightness tests of the building and/or ventilation system are quality assurance tests and hence require the involvement of an accredited third party.

→ **Inventory of lessons learned**

In the case of macro-objective B4a “Healthy and comfortable spaces”, it is difficult to treat the ventilation strategy, exposure to hazardous substances from building product emissions and exposure to hazardous substances from outdoor air sources separately. For instance, applying building materials with low emissions of hazardous substances can result in less stringent ventilation rate requirements. A holistic approach seems appropriate.

Officair formulated three key recommendations for an improved IAQ. These key recommendations are in-line with the findings of the EnVIE¹²⁷ 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':

- Limit entrance of pollutants from outdoor;
- Limit pollutants from indoor sources by choosing low emission cleaning products, building materials and furniture;
- Limit exposure by using a ventilation strategy based on health criteria.

Ventilation rates are important to set a good comfort level (cf. macro-objective B4b). However, in case of insufficient ventilation, occupant health and well-being might be negatively affected, or indoor generated pollutants may accumulate. A sufficient ventilation rate, adapted to the building, its indoor finishings and decoration, occupants and occupants behavior, is necessary to evacuate indoor contaminants, control humidity and provide fresh air in order to avoid sick building syndrome symptoms (i.e. headache, muscle ache, coughing, exhaustion, dizziness and rash). However, while ventilation standards such as EN 15251 offer the option to formulate performance targets taking into account both pollution from the occupants and pollution from the building and its systems, it seems that in practice performance targets are set as a result of an optimal energy performance or occupant pollution only.

There is a strong relationship (or in some cases, a trade-off) between the ventilation strategy and energy performance. Field studies Cleanair Lowenergy, Renovair and INSULatE focussed on this subject. As a matter of fact, EN 15251 in particular has defined indoor air parameters in order to incorporate them in energy performance calculations. Renovair and Cleanair, lowenergy focussed on improvement options of energy performance and their impact on the Indoor Air Quality. Cleanair, lowenergy in particular studied to which extent the choice and design of the ventilation system and the performance of the building envelope regarding airtightness could influence the IAQ. In the experience of the certified projects, clients tend to prioritise energy performance more than health and comfort.

Some indoor air pollutants originate from external pollution, particularly in locations with high vehicular or industrial emissions. Decisions on the location of air intakes e.g. in courtyards/patios or away from pollution sources might have an impact on the indoor air quality. EN 13779 defines outdoor air categories and filtration levels. Field studies underline the effect of filtration of intake air, as well as the maintenance of air filters; the EU Healthvent project proposed a strategy for aligning required ventilation rates to (1) outdoor pollutant levels (WHO guidelines), and (2) initiatives for selecting low-emitting building materials.

¹²⁷ EnVIE (2009) *Objectives and approach of EnVIE* [online], available at: <http://paginas.fe.up.pt/~envie/> [20/5/2016]

→ Indicator options

Table 42: 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 | | | |
| 4.1 Hazardous substances – ventilation intake | | | | | | | |
| Air Change Rate or Air Changes per Hour | m³/m²/hr | B1-7: Use | Design stage In-use | Air leakage Ventilation | EN 13829 | - | FS |
| Air tightness | n50 [m³/m³/hr] | B1-7: Use | In-use | Air leakage Ventilation | | - | FS |
| Flow rate | m³/hr | B1-7: Use | Design stage | Ventilation | EN 13779 | - | FS |
| | | | In use | | Flow rate measurements | | FS |
| Supply indoor air quality rating | IDA classes | B1-7: Use | Design stage In-use | Ventilation | EN 15251 EN 13779 | - | FS |
| Filtration classes of polluted external air | Filter classes | B1-7: Use | In-use | Ventilation | EN 13779 | Link to WHO classification of external pollution | FS |

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

Table 43: Long list of macro-objective 4a supporting indicators

| Indicator | Unit of measurement and functional unit | Scope | | | Calculation methodology and data sources | Reference conditions and rules | Source |
|---|---|------------------|---------------|---------------------|--|--------------------------------|--------|
| | | Life cycle stage | Project stage | | | | |
| 4.1 Hazardous substances – ventilation intake | | | | | | | |
| Temperature | K | B1-7: Use | In-use | Internal conditions | In-situ measurements | - | FS |
| Relative Humidity | % | B1-7: Use | In-use | | | - | FS |
| Indoor CO ₂ 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)

4.4.2. EXPOSURE TO HAZARDOUS SUBSTANCES – MATERIALS' EMISSIONS AND (DE)CONSTRUCTION OF BUILDING COMPONENTS

→ Improvement options

Concerning the exposure of hazardous substances as a result of materials' emissions, the following two strategies are identified in the field studies as common options to improve the indoor air quality: selecting and applying building materials with low emission values, and limiting the indoor air concentrations of hazardous substances. Criteria relate mainly to Volatile Organic Compounds (VOCs) and aldehydes (in particular formaldehyde).

In both the renovated and new-build office projects of ALTO, the certification schemes define performance targets that relate to the selection of low emission building materials. However, different approaches can be distinguished.

The majority of the certification schemes in the ALTO office projects tend to focus on certain product types. Depending on the product type, different emission levels and standards may apply. HQE limits the scope to building materials in contact with the indoor air in occupied spaces. BREEAM also limits the requirements to key internal finishes and fittings integral to the building (wood panels, timber structures, wood flooring, textile and laminated floor coverings, suspended ceiling tiles, flooring adhesives, wall-coverings) but excludes furniture (e.g. office desks). In particular for wood-based panels (such as OSB), BREEAM uses the formaldehyde emission classes E1 and E2 as referenced in the harmonised European standard EN 13986. LEED considers the following product categories: adhesives and sealants; paints and coatings; flooring systems; composite wood and agrifiber products.

The proportion of the surface area that has to comply, depends on the desired certification scheme and the desired performance level. For instance, HQE requires a compliance for 50%, 80% or 100% of the surface area in contact with the indoor air, to acquire respectively a base level, a performant level or a very performant level rating. BREEAM on the other hand requires a surface area proportion of 100% for five out of the seven product types to acquire credits on this criterion.

Furthermore, a two-step approach can be identified in the case of HQE. In the first step, it is sufficient to assess the VOCs or formaldehyde emissions (without the obligation of meeting a threshold level) for 50% to 100% of the indoor surfaces. In the second step, TVOC and formaldehydes limit values are defined for wall, floor and ceiling coverings. The limit values for TVOC range from 2000 µg/m³ (performant level) to 1000 µg/m³ (very performant level). The limit values for formaldehydes range from 120 µg/m³ (performant level) to 10 µg/m³ (very performant level).

DGNB uses a different approach. The certification scheme sets qualitative requirements regarding the selection of low emission building materials, in the sense that it recommends the use of environmental labels (e.g. Blaue Engel), product codes (e.g. EmiCode) or testing procedures (e.g. AgBB). It does not set specific quantitative targets for the material selection and instead refers to an indoor air quality assessment of hazardous substances.

The field studies that focussed on residential buildings (Cleanair Lowenergy and Renovair), did investigate the extent to which home owners or architects want to achieve a healthy IAQ by

choosing low-emission building materials. However, aside from the applicable EU regulations, Belgium has no mandatory product label that applies to all building products available on the Belgian market.

The WHO guidelines¹²⁸ serve as a common reference for limitations of indoor air concentrations of hazardous substances. Local regulations sometimes apply also, for instance Flemish Indoor Air guidelines¹²⁹ in the case of Cleanair Lowenergy and Renovair. In the annex of the European Standard EN 15251, an expected 'low indoor pollution level' is determined by the following criteria:

- Emissions of TVOC < 0,2 mg/m²h;
- Formaldehyde emissions < 0,05 mg/m²h;
- Ammonia emissions < 0,03 mg/m²h;
- Emissions of carcinogens < 0,005 mg/m²h;
- No odour emitting materials (dissatisfaction due to odour nuisance < 15%).

In the ALTO office projects, only DGNB stipulated threshold values for VOC and formaldehyde concentrations in the indoor air had to be verified in one or more rooms, by means of indoor air sampling methods according to ISO 16000-3 and ISO 16000-6 (see next section). The limit values for TVOC range from 3000 µg/m³ (minimum level to achieve credits) to 500 µg/m³ (highest level). The limit values for formaldehydes range from 120 µg/m³ (minimum level to achieve credits) to 60 µg/m³ (highest level).

Regarding the exposure to hazardous substances during the (de)construction of building components, DGNB makes a clear distinction between the *emission* and the *content* of hazardous substances. Regarding the content (which can be released during (de)construction of the building components), the certification scheme has defined criteria for a wide range of building materials: foundations, floor structure, external and internal walls, ceiling, roof and underground car parks. Requirements are defined for four quality classes and relate to VOC and heavy metal content, dangerous compounds etc.

→ Tools, methodologies and standards

In the **ALTO office projects**, different methodologies and standards are used and referred to by the certification schemes.

HQE refers to the ISO 16000 series, which can be seen as the key reference standards regarding indoor air quality assessments. Regarding the laboratory testing of VOC product emissions, the emission test chamber method and the emission test cell method as outlined in ISO 16000-9¹³⁰ and ISO 16000-10¹³¹ apply. In addition, HQE refers to national evaluation methods for VOC and formaldehyde assessments in France (AFSSET), Finland (M1 classification scheme) and Germany (AgBB, GUT, EMICODE).

¹²⁸ World Health Organisation. Air Quality Guidelines for Europe, WHO, 1999

¹²⁹ Flemish Indoor Environment Decree, 11th of June 2004

¹³⁰ ISO 16000-9:2006

Indoor air -- Part 9, Determination of the emission of volatile organic compounds from building products and furnishing -- Emission test chamber method

¹³¹ ISO 16000-10:2006

Indoor air -- Part 10, Determination of the emission of volatile organic compounds from building products and furnishing -- Emission test cell method

DGNB uses the German Building Product Testing and Evaluation Scheme developed by AgBB.

LEED considers the German evaluation methods to assess VOC concentrations for certification projects outside the US, although in general, it refers to American standards, such as the South Coast Air Quality Management District (SCAQMD) Rules¹³² and Green Seal Standards¹³³.

BREEAM refers to a number of standards, depending on the type of floor, wall or ceiling product.

Regarding the assessment of formaldehyde, both HQE and BREEAM specifically highlight the European standards EN 717 and EN 120, in which methods are specified to determine the content of formaldehyde in wood-based panels or its release from wood-based panels (e.g. OSB panels).

The **Officair study** not only focussed on the building materials and products used for floor, wall or ceiling coverings, but also performed laboratory tests of office furniture. This included common office furniture such as an office desk, lap-top, office chair, wall board, printer and projector but also common cleaning products such as an all-purpose cleaner and screen cleaner. The results indicated that the wall board and office desk have the largest amount of total emissions. Considering that these pieces are quite common in an office setting and typically account for several m² in an office environment, these two are the most important polluters in offices.

The methodologies mentioned to this point focus solely on product emission tests in a laboratory environment. The ISO 16000 series also includes standards with specifications for measurement tests in actual buildings. Regarding **in-situ measurements** of formaldehyde, VOC and TVOC concentrations in indoor air, the active sampling methods as specified in ISO 16000-3¹³⁴ and ISO 16000-6¹³⁵ are used. In the DGNB scheme, the indoor TVOC concentrations are determined based on these standards. DGNB puts more emphasis on these in-situ measurements than the other schemes, which cover mostly laboratory tests of building products: DGNB stipulates that measurements and chemical analyses must be conducted within four weeks after building completion and before furniture is installed. The number of rooms, which have to be measured, depends on the total number and variety of the rooms in the building.

The research projects (Officair, INSULAtE, Cleanair lowenergy and Renovair) not only conducted measurements for TVOC, VOCs and aldehydes (compounds typically related to indoor sources of pollution), but also O₃, CO₂, NO₂, PM_{2.5} and PM_x concentrations (substances typically related to outdoor sources). The methodologies used are listed for each field study in ANNEX 1 Catalogue of field studies. The different scope and building aspects covered are summarised in Table 44.

¹³² <http://www.aqmd.gov/home/regulations/rules>

¹³³ <http://www.greenseal.org/GreenBusiness/Standards.aspx>

¹³⁴ ISO 16000-3:2011, Indoor air - Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air -- Active sampling method

¹³⁵ ISO 16000-6:2011, Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID

Table 44: Overview of the different scope and building aspects covered in the field studies

| Building aspects | Scope | Methodology | Field study |
|---|---|---------------------|---------------------|
| Interior finishings: <ul style="list-style-type: none"> - Wood panels: particleboard, MDF, OSB... - Timber structures: glued laminated timber - Wood flooring - Resilient, textile and laminated floor coverings: vinyl/linoleum, cork and rubber, carpet, laminated wood flooring - Suspended ceiling tiles - Flooring adhesives - Wall coverings: wallpapers, textile or plastic wall-coverings, ... | <ul style="list-style-type: none"> - Formaldehyde - Formaldehyde - Formaldehyde - Formaldehyde - Formaldehyde, asbestos - VOCs - Formaldehyde, VCM | Product testing | BREEAM |
| Interior finishings: <ul style="list-style-type: none"> - Adhesives and sealants - Paints and coating - Flooring (except mineral-based finish floorings) - Composite wood (= building elements, not furniture or equipment) | <ul style="list-style-type: none"> - VOCs - VOCs - VOCs - Formaldehyde | Product testing | LEED |
| Interior finishings: <ul style="list-style-type: none"> - Interior surfaces (walls, floors, ceilings) (construction materials in direct contact with indoor air) - Paints and varnishes | <ul style="list-style-type: none"> - Formaldehyde, VOCs, CMRs, wood treatment - Formaldehyde, VOCs | Product testing | HQE |
| Representative room, taking into account seasonal variations (winter and summer periods) | NO ₂ , CO, Benzene, formaldehyde, PM _{2.5} and PM ₁₀ , Radon, TVOC | In-situ measurement | |
| Representative room, within four weeks after completion | Formaldehyde, TVOC | In-situ measurement | DGNB |
| Representative room during occupation, taking into account seasonal and spatial variation | VOCs, TVOC, aldehydes, particulate matter (PM _{2.5} , PM ₁₀), O ₃ , NO ₂ | In-situ measurement | Officair |
| Equipment: <ul style="list-style-type: none"> - Furniture (typical office equipment) and cleaning products | TVOC, SVOC, aldehydes, PM ₁₀ , O ₃ , Ultrafine Particles (UFP), carbonyl | Product testing | |
| Living room of single family house (new-build) | VOCs, TVOC, aldehydes, PM _{2.5} , PM _x , CO ₂ | In-situ measurement | Cleanair, Lowenergy |
| Living room of single family house (renovation) to measure impact of following renovation measures: Upgrade of windows; Façade insulation; Wall insulation; Floor insulation; Roof and ceiling insulation; Wall treatment against rising damp; Thorough energetic renovation; upgrade to mechanical ventilation system | VOCs, TVOC, aldehydes, PM _{2.5} , PM _x , CO ₂ | In-situ measurement | Renovair |

| | | | |
|--|---|---------------------|----------|
| Living room of apartment unit (renovation) | VOCs, TVOC, formaldehyde, PM _{2.5} , PM ₁₀ , CO ₂ , CO, radon, NO ₂ | In-situ measurement | INSULatE |
|--|---|---------------------|----------|

→ Data requirements

Data requirements for these aspects of the macro-objective include information on the building products used for the internal finishing of the floors, walls and ceilings: product type, quantities and technical characteristics. This concerns data on the emissions and content of hazardous substances in building products.

The field studies indicate a variety in the availability of and accessibility to this data in the building practice and among the Member States.

The Skanska projects pointed out several databases of building products in the Scandinavian countries, which focus on collecting this kind of data. Examples quoted by the Skanska Business Units include: Basta online¹³⁶, BVB¹³⁷ and Sundahus¹³⁸ in Sweden, and ProductXchange¹³⁹ in Norway. The Finnish M1 classification system in Finland and the different initiatives in Germany already mentioned also indicate the existence of such databases in Finland and Germany.

When emission or content data is not available for a building product, laboratory tests by an accredited party are necessary.

→ Processes and actors

Table 45: Processes and actors – product emissions

| Methodology | Project stage | Lead actor | Supporting actor |
|--|--|--|---|
| Selection of low-emitting building materials | Concept design, developed and technical design, construction | Architect | Environmental consultant, manufacturer During construction: contractor |
| Product testing | Construction | Accredited third party (laboratory) conducting the tests | Manufacturer, contractor |
| In-situ measurements of IAQ | Hand-over and close-out | Third party conducting the assessment | Contractor, architect, environmental consultant |

¹³⁶ Swedish Construction Federation and Swedish Environmental Research Institution (2016), Basta online, available at: <http://www.bastaonline.se/> [1/8/2016]

¹³⁷ BVB (2016) Building Product Assessment, available at: <https://www.byggvarubedomningen.se/> [1/8/2016]

¹³⁸ Sundahus (2016) Healthy Houses, available at: <https://www.sundahus.se/en/> [1/8/2016]

¹³⁹ ProductXchange, available at: <http://productxchange.com/> [1/8/2016]

Regarding the selection of low-emitting building materials and the assessment of the product emissions, the architect must depend on emission data on building products. This data is typically provided by the manufacturer in the technical information sheets of the product. Labels or classification systems provide more practical support to the architect during the concept design. Otherwise, laboratory tests by accredited third parties might be necessary, which implies an additional cost.

Regarding in-situ measurements of the IAQ, the timing of these measurements can influence the results significantly. In particular, if measurements are done before or after the installation of furniture, or pre-/post-occupation. For instance, in the case of TVOC concentrations, DGNB stipulates that the measurements have to take place no more than four weeks after building completion and before furniture is installed. Emission testing of office furniture in Officair however indicate that office furniture can be an important source of hazardous substances. Officair also indicated seasonal variations of the results (i.e. different concentrations in winter compared to the summer period). In-situ measurements can be interpreted as additional quality assurance. The measurements almost always imply an extra cost, as a third party has to conduct them.

→ Lessons learned

Selection of 'healthy' building materials is important and is generally considered as a priority over increasing ventilation rates. It is supported by three classes of measures:

- Imposed in product policy : e.g. EU Construction Product Regulation, Belgian regulation on VOC emissions from flooring products, the German AgBB and the French labelling for indoor construction products;
- Imposed in national building codes: D2 National Building Code of Finland, Ministry of the Environment, Department of Built Environment;
- Encouraged by voluntary product labels and building certifications: e.g. DGNB, LEED, EU Ecolabel, M1, Blue Angel and NaturePlus, etc.

Targets and application fields, associated to these measures, are different per instrument:

- ranging from threshold levels to the bann of a chemical;
- ranging from specific building product types (e.g. only flooring and glues in the Belgian Decree) to a broad field of application (e.g. the German AgBB, French labelling system) with different ambition levels on reducing emissions: limited (French labelling and EU Ecolabel) to very extensive restrictions (M1 label and AgBB).

The determination of the concentration levels of hazardous substances can be performed using different analytical methods and techniques, and can be expressed in various units. The ISO-16000 is identified as key standard in this regards. A clear distinction can be made between approaches which imply product emission testing and approaches which focus on in-situ air measurements. In the ALTO office projects, BREEAM and LEED focus on the former, while DGNB emphasises more on the latter. HQE covers both approaches.

In the case of product emission testing, the scope of the assessment of hazardous substances is largely focussed on VOCs and formaldehyde. This initial scope is enlarged for certain product groups: for instance, asbestos in case of ceiling tiles, wood treatments, or Vinyl Chloride Monomer (VCM), which is related to PVC products. HQE puts additional emphasis on Carcinogenic, Mutagenic

and Reprotoxic substances (CMRs) as defined in the European CLP Regulation¹⁴⁰. In general, building aspects considered include the building materials related to interior floor finishings, wall or ceiling coverings. The Officair field study is an exception, as it specifically targets the building equipment: more in particular, the typical furniture, objects and cleaning products used in offices. As a result, the assessment does not only include VOCs and formaldehyde but other substances as well, such as carbonyl, ultrafine particles (UFPs), particulate matter, ozone and nitrogen dioxide, as these are understood to be linked to certain product groups such as printers or cleaning products.

In the case of in-situ air measurements, it is observed that the scope of the assessment of hazardous substances is broader. In addition to formaldehyde and VOCs, the following pollutants are included in the assessment of at least one field study: CO, CO₂, NO₂, O₃, particulate matter (PM_{2.5}, PM_x and PM₁₀) and Radon. Furthermore, the total VOC-level (TVOC) can be calculated as well. Based on the experience of the field studies, it is clear that the choice of the timing of the in-situ measurements is very important to have representative and meaningful results. For instance, in Officair, seasonal variations in winter and summer were observed. An issue is whether in-situ IAQ testing is carried out for unoccupied (post-completion) or occupied spaces. DGNB specifically requires an in-situ measurement within four weeks after completion, before occupation of the building in order to be representative of the building itself (without equipment). Furthermore, the location of the assessment has an influence as well. In Officair, spatial variations were observed in the building itself: IAQ-measurements on lower storeys differed significantly from IAQ-measurements on upper storeys as a result of external pollution on street level. Both DGNB and HQE require that the in-situ measurements be conducted in a representative room (for instance, office rooms in office buildings). In the field studies that focussed on residential buildings, measurements were conducted in the living rooms.

In the majority of the field studies, substances such as VOCs and formaldehydes are typically related to “indoor” sources of pollution, while substances such as O₃ and NO₂ are identified as “outdoor” pollutants. However, this is not always the case, as illustrated in the Officair assessment of office equipment, where particulate matter was linked to an indoor source (i.e. printers). This indicates that caution is needed when classifying certain hazardous substances as “indoor” pollutant or “outdoor” pollutant, just on the basis of its type. The ratio of indoor and outdoor concentrations of pollutants (I/O-ratio) can be a supporting indicator in this regard. However, as this indicator requires not only indoor but also outdoor measurements, it seems limited to research studies and does not seem feasible to assess in a common building project.

Regarding the experience from the certified projects of ALTO, it is observed that the HQE requirements are not difficulties to attain. In particular, the two-step approach of the HQE targets (first step: require an assessment without quantitative targets; second step: define quantitative performance targets or benchmarks) seems to be successful in the sense that it allows the building practice (in particular product manufacturers) to become familiar with the assessment methodology.

The approach of HQE and DGNB distinguishes itself from the other certification schemes as it requires in-situ measurements (however, it is recently introduced in BREEAM assessments too). Only a few field studies however provided results from measurement of VOC emissions post-completion. Such post-completion measurement were conducted in one of the ALTO office projects, one month after completion but before occupation. The results are still good on average

¹⁴⁰ REGULATION (EC) No 1272/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006

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 city center entered the building. Furthermore, the measurement conditions were not ideal: carpets as well as crawlspaces and ventilation channels were not cleaned well, windows were opened and as result external pollution entered the building before the ventilation's commissioning.

It is difficult to identify the approach which is best in terms of minimising risk of exposure. The majority of criteria in each of the certification schemes target indoor finishings, but there is no clearly defined priority list. This should clearly relate to the goal of the assessment: does the assessment target the building, the interior or the equipment? The field studies indicate a strong relationship between the building/equipment aspects that are considered, the assessment method and the scope of the hazardous substances. For instance, when furniture and room equipment is considered, it makes sense to not only consider VOC and formaldehyde, but other substances as well such as UFPs or PMs (which are emitted by printers) or ozone (in case of cleaning products). In addition, it is difficult to capture the influence of user behaviour and context factors (for instance the location of the building and possible external pollution related to it), although these factors can have a significant impact on the indoor air quality, despite dedicated efforts in applying low-emission materials, an adapted ventilation strategy and measures for air intake.

→ Indicator options

Table 46: 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 | | | |
| 4.2 Hazardous substances – source control | | | | | | | |
| Indoor air pollutant concentrations | µg.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 |
| Rating or classification system for building materials | Emissions class, R Value and/or µg.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 ¹⁴¹ , SUNDAHUS ¹⁴² (Sweden)) | - | FS AR CC |

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

| 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 | | | |
| 4.2 Hazardous substances – source control | | | | | | | |
| I/O ratio (indoor/outdoor ratio of pollutant concentrations) | [dimensionless] | B1-7: Use | In-use | Ventilation | EN 13779 | VOCs, TVOCs, aldehydes, particulate matter (PM _{2.5} , PM _x , PM ₁₀), CO ₂ | FS |

¹⁴¹ BASTA (2016) *About Basta* [online], available at: <http://www.bastaonline.se/about-basta/about-basta/?lang=en> [20/5/2016]

¹⁴² SUNDAHUS (2016) *Efficient solutions for conscious material choices* [online], available at: <https://www.sundahus.se/en/> [20/5/2016]

4.4.3. MOISTURE AND MOULD

→ Improvement options

Improvement options focus on the prevention of mould and moisture causes and resulted damage.

In the refurbished ALTO office project, mould and moisture were measured using the French standard AFNOR XP X 43-401 for the assessment. It provides a range of recommended values for bacteria and fungi concentrations in the case of office buildings (see Table 47).

Table 47: Performance targets for bacteria and fungi concentrations in offices, expressed in Colony Forming Units (CFU) per m³ (source: French standard AFNOR XP X 43-401 – annex A.4 (1998)¹⁴³)

| | Bacteria concentrations (CFU/m ³) | | Fungi concentrations (CFU/m ³) | |
|---------------|---|---------|--|---------|
| | offices | outside | offices | outside |
| percentile 5 | 95 | 25 | 3 | 17 |
| percentile 50 | 320 | 70 | 6 | 61 |
| percentile 95 | 1020 | 281 | 45 | 257 |
| maximum | 3150 | 860 | 710 | 675 |
| minimum | 15 | 15 | 1 | < 1 |

Cleanair Lowenergy referred to the Flemish Indoor Environment Decree of 11/06/2014¹⁴⁴, which puts forward guideline values for biological parameters including micro-organisms and fungi.

Table 48: Guideline values for biological parameters according to the Flemish Indoor Environment Decree of 11/06/2014 (source: Flemish Government (2014))

| Compound / factor | Guideline value |
|----------------------|--------------------------|
| house dust mite | ≤ 0.2 mg guanine/g dust |
| cockroach | < 1 per building |
| micro-organisms | ≤ 500 CFU/m ³ |
| mites | |
| - In floor covering | ≤ 10/g dust |
| - In bed / furniture | ≤ 100/g dust |
| rat / mouse | < 1 per building |
| fungi | ≤ 200 CFU/m ³ |

The field studies that cover residential refurbishment projects (i.e. Renovair and INSULatE) emphasis on qualitative criteria and not only on quantitative target values, for instance visual observations of mould and moisture damage.

¹⁴³ XP X 43-401 (1998) *Indoor Air Quality – IAQ assessment in non-industrial spaces – office buildings*, AFNOR

¹⁴⁴ an update of the Flemish Indoor Environment Decree will be published by the end of 2016

→ Tools, methodologies and standards

In the Cleanair, Lowenergy biological agents were assessed by using air samples and surface samples of settled dust. In Renovair and INSULatE, surface samples were collected but no air samples. In Renovair, a visual inspection of fungi and moisture problems was conducted using a walk-through survey based on a checklist for building inspection that was developed under the framework of the HITEA study. The microbial pollutants addressed in Cleanair, Lowenergy were bacteria, fungi and yeast. The microbial pollutants addressed in Renovair and INSULatE were bacteria and fungi.

Regarding the air samples, sampling was performed in the living room, the bedroom as well as in the garden; at school, sampling was performed in each selected classroom, as well as on the playground. All samples were collected during the same house or school visit. Samples were collected in the middle of the room, at a height of 1-1.5m. The analysis of the samples were conducted according to ISO 21527-1¹⁴⁵ in case of the total fungi and yeasts, and ISO 4833¹⁴⁶ in case of the total bacteria.

Regarding the surface samples of settled dust, houses received a post package, containing (1) two Petri dishes with a surface of 15 cm for houses; (2) a letter with instructions and explanations (see Annex); (3) a questionnaire for biological measurements. The participants were instructed to open the Petri dishes and to install two halves in the living room and two halves in the bedroom for residences. The Petri dish should be installed at a height of 1.5 m, be out of reach of children and pets (the inside of the dish should not be touched), and should not be closer than 1 meter to a window or door opening. When the dishes were installed, a printed document saying '*Please don't touch or move*', was installed next to it. Any incident should be reported on the questionnaire for biological measurements. The samples were exposed for one week (7 days). The sampling analysis of the yeast and fungi and the total bacteria was performed in agreement with ISO 21527-1¹⁴⁵ and ISO 4833¹⁴⁶ respectively.

The approach of the building inspection on mould and moisture issues, which was conducted in the HITEA study and formed the basis of the survey used in Renovair, is described in a publication of Ulla Haverinen-Shaughnessy¹⁴⁷. In a first step, a questionnaire survey was circulated to school principals and the responsible persons for the maintenance of their school building (in the case of HITEA, school buildings but the approach can easily be applied on other building types as well) to screen the buildings on moisture damage and dampness problems. The questionnaire contained ten key questions on current and past dampness, moisture and mould observations and collected background information on building and ventilation characteristics. In a second step, on-site building inspections were conducted by trained research personnel that included walkthroughs with pre-designed checklists and non-destructive measurements such as hand-held moisture detection, relative humidity, temperature and CO₂ monitoring.

A comprehensive framework for mould and moisture assessments in existing buildings with an overview of possible measurement methods is provided by a publication of Haverinen-

¹⁴⁵ ISO 21527-1 (2008) Microbiology of food and animal feeding stuffs -- Horizontal method for the enumeration of yeasts and moulds -- Part 1: Colony count technique in products with water activity greater than 0,95

¹⁴⁶ ISO 4833 (2013) Microbiology of the food chain -- Horizontal method for the enumeration of microorganisms

¹⁴⁷ Haverinen-Shaughnessy, U. et al., 2012, *Occurrence of moisture problems in schools in three countries from different climatic regions of Europe based on questionnaires and building inspections - the HITEA study*, Indoor Air, 2012 Dec;22(6):457-66

Shaughnessy et al.¹⁴⁸ In addition to the non-destructive techniques already mentioned (air and surface sampling, accompanied by surveys or walkthroughs), destructive methods are mentioned if during the inspection there were locations suspected to have new damage, or if the damage was suspected to be repaired unsatisfactory. Furthermore, the importance of paying attention to timing and location of samples was highlighted (for instance measurements during winter and summer). Finally, the author points out the importance of continuous maintenance as the best follow-up practice to ensure the success of repair measures taken during the building lifespan¹⁴⁹.

→ Data requirements

Data of concentrations of biological agents is collected on-site using air or dust sampling.

Data of building characteristics (with an emphasis on the building construction, building envelope and technical installations such as the ventilation system) can be collected during an on-site inspection in combination with available documentation of the building, or through surveys with the building manager or building occupant.

→ Processes and actors

Table 49: Processes and actors – Moisture and mould

| Methodology | Project stage | Lead actor | Supporting actor |
|------------------------------|---------------------|--|--|
| Survey | In-use | Building manager | Occupant |
| Walkthrough checklist | In-use | Trained professional for building inspection (architect, contractor) | Occupant, building owner, building manager |
| Air and/or dust sampling | In-use | Accredited third party | Occupant |
| Follow-up during maintenance | In-use, maintenance | Building manager, occupant | - |

The field studies analysed focussed mainly on remediation of mould and moisture issues. A variety of methods and techniques that can be applied during the in-use phase of the building were identified. The methods listed were already discussed in the section “Tools, methodologies and standards”.

Nevertheless, building actors such as architects and contractors have an important role during the design and construction of the building to prevent mould and moisture issues, although the field studies did not specifically provide evidence regarding this.

¹⁴⁸ Haverinen-Shaughnessy, U., Hyvärinen, A., Putus, T., Nevalainen, A., (2008), *Monitoring success of remediation: Seven case studies of moisture and mold damaged buildings, science of the total environment*, 399 (2008) 19-27

¹⁴⁹ Hiipakka DW, Buffington JR. *Resolution of sick building syndrome in a higsecurity facility. Appl Occup Environ Hyg* 2000; 15:635-43

→ Inventory of lessons learned

Measurement of damp and mould is a relatively new area, and it appears that test methods to evaluate levels in-situ are relatively undeveloped for widespread use. Some Member States have run extensive programmes to tackle problems in existing buildings, for instance the national mould and moisture programme in Finland¹⁵⁰. However, it appears to have focussed more on training and guidance.

With regards to renovation projects, according to the Renovair data, thermal bridges present before the renovation are in some cases even more pronounced after renovation. The airtightness 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 Finnish moisture and mould programme.

Finally, the publication of Haverinen-Shaughnessy et al.¹⁴⁸ pointed out that in some of the case studies, no improvement could be observed in IAQ or occupant health, even if technical remediation measures to address mould and moisture issues had taken place successfully. Possible reasons that are quoted include: 1) all damage may not have been addressed adequately; 2) IAQ or health may not have been perceived improved regardless of remediation; and/or 3) the methods used may not have been sensitive/specific enough to detect such improvement within the assessment period.

¹⁵⁰ Finnish Ministry of the Environment, 2014, *Moisture and mould programme*, accessible at: <http://uutiset.hometalkoot.fi/en/home.html> [1/8/2016]

→ Indicator options

Table 50: 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 | | | |
| Concentration of biological agents (fungi, yeast and total bacteria) | CFU/m ³ CFU: Colony Forming Units | B1-7: Use | In-use Handover and close-out Refurbishment In-use | In situ air quality | French standard: AFNOR XP X 43-401 | - | FS |
| Inspection classification of dampness and mould in building structures | Rating or classification | B1-7: Use | | Internal conditions | Member State rating systems e.g. Nordic proposal, classes 1-4 | - | CC |

Supporting indicators

Table 51: Long list of macro-objective 4a supporting 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 | | | |
| Temperature | K | B1-7: Use | In-use | Internal conditions | In-situ measurements | - | FS |
| Relative Humidity | % | B1-7: Use | In-use | | | - | FS |
| Indoor CO ₂ concentration | ppm | B1-7: Use | In-use | | | - | FS |

4.5. RESILIENCE TO CLIMATE CHANGE (MACRO-OBJECTIVE B5)

Macro-objective B5 “Resilience to climate change” covers the future-proofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort. The focus of this macro-objective at building level has been identified as relating to thermal comfort, with EU strategy highlighting the need to integrate consideration of overheating into building standards. The simulated tolerance of building designs is therefore the main focus. The scope could also consider the potential for ‘green infrastructure’ at building level, for which there is evidence that certain features can improve the thermal tolerance of buildings and their surrounding microclimate.

Summary of aspects covered:

- Thermal tolerance
- Green infrastructures

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:

- o Design for Future Change: Office building adaptation modelling (UK);
- o Knowledge for Climate: Residential building adaptation modelling (Netherlands);
- o IDOM and New4Old: Office and residential building adaptation modelling and design (Spain).

The field study analysis focusses mainly on the aspect of thermal tolerance. Nevertheless, three cross-check studies are included in Annex II to explore the aspect of green infrastructures:

- o Biotope Area Factor: Green space requirements in Berlin (Germany);
- o Green Space Factor and Green Point System: Green space requirements in Stockholm and Malmö (Sweden);
- o Green roof building regulation in Basel (Switzerland).

4.5.1. THERMAL TOLERANCE

→ Improvement options

To assess the thermal tolerance of buildings in the future climate, two major components have to be taken into account: the assessment of thermal comfort, and the use of future climate projections and scenarios.

Regarding thermal comfort, key standards are the European standard EN 15251 and the American standard ASHRAE 55. The Center for the Built Environment of the University of California in Berkeley (CBE) has developed a free online tool (CBE Thermal Comfort Tool) that allows to assess and compare the thermal comfort results according to the two standards and can be used to verify LEED compliance¹⁵¹. In the UK, CIBSE Guide A is used as key reference, which refers to EN 15251.

¹⁵¹ BUILD UP (2013), Center for the Built Environment – CBE thermal comfort tool, available at: <http://www.buildup.eu/hr/node/38912> [1/8/2016]

Performance targets are set based to the thermal comfort targets of these standards. For instance, in case of one of the Design for Future Climate projects: no more than 5% of occupied hours exceeding 25°C, no more than 1% of occupied hours exceeding 28°C.

Regarding the reference and future climate projections, thermal comfort calculations are conducted for a baseline scenario and one or more future climate scenarios in the field studies. However, there were no specific standards or certification criteria identified in the field studies with common guidelines concerning the use of these climate scenarios. The UK can be seen as a front-runner in this field, as illustrated in the Design for Future Climate field study in which the UKCP09 climate data projections were used in combination with the CIBSE Test Reference Year (TRY) and probabilistic Design Summer Years (DSY) data.

In practice, improvement options relate to: building envelope measures (with focus on preventing heat gains by applying solar shading and glazing), thermal capacity of the building (thermal mass, green roofs), technical installations (passive cooling strategies and ventilation) or user behaviour (operational measures, user adaptation). Performance targets for these improvement options either relate to energy performance targets or the thermal comfort targets as discussed earlier.

→ **Tools, methodologies and standards**

Table 52: Tools, methodologies and standards

| Methodology used | Tools used | Standards used |
|--|--|--|
| Dynamic simulation using future weather data | Open-source tools: Energy Plus Commercial tools (e.g. IES virtual environment) | CIBSE Guide A (2006); EN 15251 ASHRAE 55 ISO 7730 |
| Future weather data | UKCP09 climate projections CIBSE current and future TRY and DSY weather data sets | UKCP09 CIBSE ISO 15927-4 |
| | Commercial software (e.g. Meteonorm) current and future weather data sets | - |
| | Weather data from a warmer than typical year in the past that can be representative for the future | - |

Once again, a distinction can be made between the assessment of the thermal comfort and the use of future climate projections.

Except for the NEW4OLD field study, all field studies used dynamic simulations to calculate the risk of overheating and to assess the thermal comfort, as the tools used for the simulations allow to use alternative (i.e. future) weather data. Quoted software tools are commercial tools or EnergyPlus, an open-source energy simulation tool used for thermal calculations.

Regarding thermal comfort, key standards are the European standard EN 15251 and the American standard ASHRAE 55, as already indicated. Specifically in the UK, the CIBSE Guide A provides additional guidance for assessing thermal comfort. Two approaches are used regarding thermal comfort: static approach (PMV (predicted mean vote) and PPD (predicted percentage of

dissatisfied) in-line with ISO 7730¹⁵²) and adaptive approach. In the static approach, any set point temperature is constant throughout the whole year. The adaptive method assumes that people make adjustments themselves, for instance in terms of clothing, activity and posture, to adapt to different circumstances. In the adaptive approach assumptions regarding indoor comfort temperature thresholds hence change with the daily or monthly outdoor temperatures. The importance of implementing adaptive thermal comfort models, especially in large scale office buildings, are highlighted in climate change impact case studies. Adaptive thermal comfort can be exploited by designers to make buildings more resilient towards climate change by providing opportunities for occupants to make adjustments to their behaviors in response to the changing environment. Specific conditions of implementing adaptive method are as follows:

- ASHRAE: *Adaptive method is applicable only for occupant-controlled naturally conditioned spaces that meet all of the following criteria: (a) There is no mechanical cooling system installed. No heating system is in operation; (b) Metabolic rates ranging from 1.0 to 1.3 met; and (c) Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5-1.0 clo.*¹⁵³
- EN 15251: *Adaptive method is applicable only for buildings without mechanical cooling systems and where there is easy access to operable windows and occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions. The criteria for the spaces are the following: (a) There is no mechanical cooling or heating system in operation; (b) Metabolic rates ranging from 1.0 to 1.3 met; (c) Occupants are allowed to freely adapt their clothing insulation.*¹⁵⁴

Adaptive thermal comfort method is applicable for naturally ventilated buildings, therefore in general it is more applicable for residential buildings where occupants have direct control of window openings for natural ventilation. Besides, some large scale office buildings are designed with natural ventilation, while the importance of implementing adaptive methods in these types of office buildings is also highlighted in climate change impact case studies, and some specific measures including flexible dressing code, direct control of natural ventilation systems and staff awareness increase.

Regarding the use of future climate projections, this differs among the field studies. As already mentioned, in the UK the UKCP09 climate projections are used in combination with CIBSE's TRY and DSY weather data sets. In the practice of IDOM, UKCP09 climate scenarios are used as well, in addition to commercial sources such as METEONORM software and its "future" weather profile feature. The Knowledge for Climate field study uses weather data from a year in the past which was much warmer than normal as a representation of the future climate, instead of using predicted future weather data (in this case, the year 2006 was chosen as several heat waves occurred that year in the Netherlands).

It is valuable to look further into the UKCP09 and CIBSE TRY and DSY weather data sets, as these are identified as the most reliable and scientifically based.

¹⁵² ISO 7730 (2005), Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

¹⁵³ ASHRAE Standard 55 (2013), Thermal Environmental Conditions for Human Occupancy

¹⁵⁴ EN 15251 (2012), Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

The UKCP09 climate scenarios are probabilistic climate projections¹⁵⁵. This information is composed from thousands of plausible climate scenarios, derived from a set of climate models. It has to be taken into account that the UKCP09 climate scenarios concern *projections* and not *predictions* in the sense that they are presented as probability distributions, rather than as single values. Temperature change below the 10% probability level is very unlikely, as is a temperature change above the 90% probability level.

The TRY weather file represents a typical year and is used to determine average energy usage within buildings. The weather file consists of typical months selected from a historical baseline (i.e. period of 1984 to 2004). The method is in-line with the Standard ISO 15927-4¹⁵⁶

The DSY represents a warmer than typical year and is used to evaluate overheating risks within buildings¹⁵⁷. The previous methodology for selecting the DSY involved calculating the mean temperature over the period April to September for each year in a baseline dataset (i.e. period of 1984 to 2004). In this case the DSY was chosen as the third hottest year. An updated methodology, however, uses a probabilistic framework for Design Summer Years¹⁵⁸.

→ Data requirements

A critical factor regarding the data requirements for assessing the thermal tolerance of buildings in a changing climate, is the availability of reliable weather data sets, both for the baseline and future conditions. As pointed out in previous sections, the UK is front-runner in this field, with the UKCP09 climate scenarios and the CIBSE weather data sets.

Table 53: Overview of available CIBSE weather data sets (source: CIBSE, 2016)

| | |
|-------------------|--|
| Current condition | TRY/DSY Hourly Weather Data |
| Future condition | TRY/DSY Hourly Weather Data for three time periods (2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100)), for the following emissions scenarios: <ul style="list-style-type: none"> - 2020s – High emissions scenario – 10th, 50th, 90th percentile, - 2050s – Medium – 10th, 50th, 90th, - 2050s – High – 10th, 50th, 90th, - 2080s – Low, 10th, 50th, 90th, - 2080s – Medium – 10th, 50th, 90th, - 2080s – High – 10th, 50th, 90th. |

¹⁵⁵ UKCP (2014), Probability in the UK Climate Projections, accessible at <http://ukclimateprojections.metoffice.gov.uk/21679> [1/8/2016]

¹⁵⁶ ISO 15927-4 (2005), Hygrothermal performance of buildings -- Calculation and presentation of climatic data - Part 4: Hourly data for assessing the annual energy use for heating and cooling

¹⁵⁷ Eames, M. and Virk, D. (2016) CIBSE Weather Files 2016 release: Technical Briefing and Testing

¹⁵⁸ Eames, M., (2016), An update of the UK's Design Summer Years Probabilistic Design Summer Years for Enhanced Overheating Risk Analysis in Building Design, Building Services Engineering Research & Technology

→ **Processes and actors***Table 54: Processes and actors – thermal tolerance*

| Methodology | Stage | Lead actor | Supporting actor |
|---|--|------------------------------------|----------------------------------|
| Dynamic simulation using future weather data | Concept design, Developed and technical design | Environmental/energy consultant | Architect, technical engineer |

In the analysed field studies, the dynamic simulations were conducted in the design process. While they can be performed as early as in the concept design. In practice, it is likely that they take place during the technical design, when there are more design options fixed.

In the field studies, the dynamic simulations using future weather data were performed by experts (dynamic simulation modellers, researcher, specialized engineering firms) as these calculations are reported to be complex and thus are likely to require specific skills and efforts.

→ **Inventory of lessons learned**

The tools, methodologies and indicators are similar to the ones typically used for thermal comfort. The main difference is the use of weather data sets to simulate future scenarios (e.g. 2030, 2050 or 2080). The versions of the certification schemes applied in the ALTO field studies focus on thermal comfort but do not specify requirements concerning the use of climate projections. Recent versions begin to address this, for instance BREEAM.

The simulation software uses dynamic simulation tools (e.g. EnergyPlus). In other words, tools that can use alternative weather files for the calculations. Future weather data to be used in the calculations can be obtained from commercial or public sources. Highly valuable sources identified in the field studies are the UKCP09 climate projections and the CIBSE current and future weather TRY and DSY data-sets, which provide projections for future temperature and solar radiation among other parameters. As a result, there is a large dependency on availability of this future climate data. Further investigation is needed to determine at which extent future climate data, comparable to the UKCP09 and CIBSE data-sets in the UK, is also available for other European regions. An alternative could be to use historic weather data to represent future conditions (as was the case in the Knowledge for Climate field study). However, the probabilistic approach of the UKCP09 and CIBSE data series are likely to provide a more stable and reliable basis for the simulations.

The most relevant indicators are temperature and overheating hours (degree hours are the product of these two indicators). The supporting indicators listed do influence thermal comfort but are not practical to use (for instance, relative humidity and air velocity require in-situ measurements). Overheating is also incorporated in energy performance regulation in selected Member States (e.g. calculation of overheating indicators using EPBD-tools (i.e. quasi-steady state simulations). These steady-state simulation tools also address thermal comfort, although they do not seem to allow simulations using projected climate data.

Finally, the level of thermal comfort in office buildings differs from the level of thermal comfort that people experience in their homes. This is caused by several factors. Residents have different activity levels than occupants in office building 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 furniture. 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).

→ Indicator options

Table 55: Long list of macro-objective 5 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 | | | |
| 5.1 Interior resilience (thermal comfort and additional cooling energy) | | | | | | | |
| Temperature | °C | B1-7: Use | Concept design Technical design | Operative temperature Upper limit temperature <ul style="list-style-type: none">- 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 |
| Overheating hours / Overheating risks (rate) | [h] or [%] | B1-7: Use | Concept design Technical design | - | Dynamic modeling using future weather data (e.g. UKCP09 ^{Error! Bookmark not defined.}) or representative weather data | | FS AR CC |
| Comfort levels | PMV-PPD (Predicted Mean Vote - Predicted Percentage of Dissatisfied) | B1-7: Use | Concept design Technical design | - | ISO 7730/15251 ASHRAE STD 55 | | AR CC |
| Degree hour | [°C*h] | B1-7: Use | Concept design Technical design | - | Product of temperature and overheating hours | | FS |

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

Table 56: 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 | | | | |
| 5.1 Interior resilience | | | | | | | |
| Relative humidity | % | B1-7: Use | In-use | See 'macro-objective 4 healthy and comfortable spaces' | | | FS |
| Flow rate | m³/h | B1-7: Use | In-use | | | | FS |

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

4.5.2. GREEN INFRASTRUCTURES

→ Improvement options

Target values are formulated for the Biotope Area Factor (BAF), depending on the building type (residential, commercial, public function) and the site occupancy index. The latter is calculated on the basis of the surface area of the site.

As an illustration, following target values are put forward for existing residential sites¹⁵⁹:

1. Sites with a site occupancy index of 0.37: BAF of 0.60 minimum
2. Sites with a site occupancy index of 0.38 up to 0.49: BAF of 0.45 minimum
3. Sites with a site occupancy index of 0.5 and over: BAF of 0.30 minimum
4. Sites within key areas on which individual stories of the buildings are used for commercial purposes: BAF of 0.30 minimum
5. Sites outside key areas on which individual stories of the buildings are used for commercial purposes should be classified as n°1 or n°2.

A BAF for sites used exclusively for commercial / industrial purposes is set at 0.3 or 0.6.

In Sweden, the Green Space Factor is used. The GSF follows the same logic as the BAF, although it specifies more types of greenery and corresponding ecological values. The target for the GSF is set at 0.5. However, the GSF is complemented with the Green Points system: a checklist of 35 items of which minimum 10 items have to be selected and applied.

→ Tools, methodologies and standards

Different types of green spaces are weighted differently according to their “ecological value”, based on evapotranspiration capacity, permeability, possibility to store rainwater, relationship to soil functioning and provision of habitat for plants and animals. Surfaces with vegetation, connected to soil below have the maximum weighting factor of 1.0; sealed surfaces have a factor of 0.0. Building-related greenery have a factor of 0.5 or 0.7 for green walls (up to a maximum of 10 m in height) and green roofs, respectively. The Swedish GSF follows the same logic as the BAF, although it specifies more types of greenery and corresponding ecological values.

The checklist of the green points system consists of 35 items. The majority of items in this checklist relate to water management and biodiversity of fauna and flora. Nevertheless, a number of items cover specific building characteristics, for instance:

4. No surfaces in the courtyard are sealed, and all surfaces are permeable to water
7. All walls, where possible, are covered with climbing plants
25. Greywater is treated in the courtyard and reused
27. Only recycled construction materials are used in the courtyard
35. All the buildings have green roofs

¹⁵⁹ Landschaft Planen & Bauen, Becker, G., Mohren, R., 1990, *The Biotope Area Factor as an ecological parameter – Principles for its determination and identification of the target*, available at: http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/bff/download/Auszug_BFF_Gutachten_1990_eng.pdf [1/8/2016]

→ **Data requirements**

Data requirements mainly concern surface area of the greenery and information on the type of greenery (in order to determine the weighting factor).

→ **Processes and actors**

Table 57: Processes and actors – Green infrastructure

| Methodology | Project stage | Lead actor | Supporting actor |
|---|----------------------|--|------------------|
| Specify targets for green factors | Definition and brief | Local authorities, property developers | Building clients |
| Include green measures in the building or building site | Concept design | Architect, landscape designer | Building client |

Basel passed a Building and Construction Law requiring green roofs on all new developments with flat roofs. An amendment, passed in 2002, reads that all new and renovated flat roofs must be greened and also stipulates their design to maximise the biodiversity.

→ **Inventory of lessons learned**

While it is understood that the BAF can be an important tool to anticipate on heat waves and water-related extremes by encouraging measures that help to lower the temperatures and improve the runoff management of building sites, the BAF seems to serve mostly landscape- and urban-planning purposes, as well as ecosystem preservation. The BAF, GSF and the green point system are especially useful to indicate the quantity of greenery and to a certain extent the quality of greenery (by making use of weighting factors). They can incentivise building clients, local authorities and/or property developers to implement measures that will have an influence on the future microclimate on the individual building/site.

However, although the results of the Basel green roof regulation indicate that there is a positive effect on energy consumption and urban heat effects, none of these indicators really capture the specific impact of “green” measures to the energy consumption or thermal comfort of the building. In order to be able to calculate this, other tools or methodologies are likely required, such as dynamic simulations. But even in the case of dynamic simulations, it might be difficult or complex to integrate certain aspects related to vegetation, for instance modeling the effect of shadows caused by trees in summer and in the winter.

→ Indicator options

Table 58: Long list of macro-objective 5 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 | | | |
| 5.2 Exterior resilience (microclimate moderation) | | | | | | | |
| Shading of the building | Cooling energy saved (kWh/m²) | 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 |
| Green Space Factor | 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)

Table 59: Long list of macro-objective 5 supporting indicators

| Indicator | Unit of measurement and functional unit | Scope | | | Calculation methodology and data sources | Reference conditions and rules | Source |
|-------------------------|---|------------------|------------------------------------|----------------------------------|--|--------------------------------|--------|
| | | Life cycle stage | Project stage | | | | |
| 5.2 Exterior resilience | | | | | | | |
| Green points | Sum of green features | B1-7: Use | Concept design Technical design | All spaces and building surfaces | Methodologies developed for city planning/permitting | - | FS |

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

4.6. OPTIMISED LIFE CYCLE COST AND VALUE (MACRO-OBJECTIVE B6)

Macro-objective B6 focusses on the optimisation of the life cycle cost and value of buildings, including acquisition, operation, maintenance and disposal. Life Cycle Costing (LCC) is an important tool during the project definition, concept design and detailed design stages, where it can be used by the designer/engineer to select and value the design that will provide the lowest overall cost (and highest residual value) along the life-cycle of the asset. It 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 development appraisals, property market valuations and mortgage calculations will also be examined.

Summary of aspects covered:

- LCC;
- Property value.

The macro-objective B6 field studies consist of three 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).

In addition, three cross-check studies are considered in the analysis:

- SuFiQuaD: an LCA/LCC study for residential property in Belgium;
- ReValue and RenoValue: two collaborative EU studies of valuation techniques.

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

4.6.1. LIFE CYCLE COST

→ Improvement options

Life Cycle Cost (LCC) analyses can be used for a number of purposes, as demonstrated in the Davis Langdon case studies. Identified applications in this study included:

- Support the choice of building materials, components or systems and assessment of their financial implications;
- Inform strategic decisions such as new build or refurbishment;
- Outline business cases;
- Procurement and assessment of future costs purposes such as maintenance, operation and management costs;
- Post competition evaluation to assess the proposed solutions; and
- Retrospective comparison of actual operational costs in relation with original LCC assessment.

In the **ALTO office projects**, only the LCC-criteria of BREEAM and DGNB were addressed. As a result, only the BREEAM and DGNB are discussed.

In **BREEAM**, an LCC analysis has to be conducted on building component level. More specifically, the analysis has to be conducted for two out of the following four categories: Structure, Envelope, Services or Finishes. For each category, at least two possible options have to be assessed. The option with the lowest discounted Life Cycle Cost over the study period (25 or 30 and 60 years) has to be selected, taken into account one of the following four complementary criteria:

1. The lowest building energy consumption over the operational life-span of the building (compared to other options/alternatives analysed);
2. A reduction in maintenance requirement/frequency;
3. Prolonged replacement intervals of services infrastructure/systems or building fabric;
4. Dismantling and recycling or reuse of building components.

Note that more recent versions of BREEAM (e.g. BREEAM 2013) have evolved and now require an LCC analysis of the whole building.

In **DGNB**, an LCC analysis on building level has to be performed. The certification scheme defined benchmark values for the Life Cycle Cost for three building categories. Buildings of the second category ("building with exceptional conditions") correspond with ambitious buildings with higher "prestige", such as the use of durable, high value materials, hot-spot locations or higher standard of technical equipment.

Table 60: Benchmark values for the Life Cycle Cost for different building categories (source: DGNB core and offices, 2014)

| Building category | Limit value | Target value |
|---------------------------------------|-----------------------------|-----------------------------|
| Building of average standard | 3.720 €/m ² .GFA | 2.100 €/m ² .GFA |
| Building with exceptional conditions | 3.853 €/m ² .GFA | 2.300 €/m ² .GFA |
| High rise building with more than 60m | 4.553 €/m ² .GFA | 3.000 €/m ² .GFA |

→ Tools, methodologies and standards

ISO 15686-5 seems to be the key standard, as it is referenced in all field studies analysed.

The EU LCC Methodology is a common European-wide methodology developed within the study of Davis Langdon and based on ISO 15686-5.

The calculation methodology of BREEAM refers to ISO 15686 as already mentioned.

The LCC analysis consists of two steps:

1. Conduct an LCC-study on different options of two out of four categories (structure, envelope, services, finishings);
2. Select the best LCC-option (according to lowest LCC and one of the four following criteria: either lowest frequency of maintenance, repair cycles reduces, lower energy performance, easier dismantling and recycling of building component).

Costs that have to be included are costs related to the following life cycle stages: construction, operation (including energy and water costs), maintenance (including maintenance, replacements,

repairs, cleaning, management costs) and end of life. Lifespans are a period of 25 or 30 years (as applicable) and 60 years.

The calculation methodology of DGNB refers to the aforementioned ISO-standard as well. The LCC Analysis has to be conducted on a building level, for a default lifespan of 50 years, according to the ISO standard. Costs that have to be included are costs related to the construction, in-use stage and end of life. The costs related to the in-use stage consist of:

- Selected operation costs (supply and disposal, cleaning, energy consumption, operation, inspection, and maintenance);
- Selected maintenance costs;

Costs related to end-of-life include Selected dismantling and disposal costs.

→ Data requirements

Data requirements in order to perform LCC, are cost data figures. Based on the experience of the field studies, the main data gap seems to be cost data related to operation and maintenance.

The DGNB certification scheme provides default-values for occupancy costs to support the calculation.

In the LCC-data study, a distinction was made between Level 1 and Level 2 calculations:

- Level 1 LCC uses statistical data such as the generic database developed within this project. Level 1 calculations are most relevant in the planning phase.
- Level 2 LCC 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 the (preliminary or technical) design phase.

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 (= operational) costs are often taken from level 1 LCC calculations, as more reliable information is rarely available.

→ Processes and actors

LCC analysis is reported to be often too time-demanding or too complex for the stakeholders (e.g. architects, engineers, large property owners).

The database for benchmarking life cycle costs of building projects, developed as part of LCC-data, had as purpose to overcome this barrier and to make LCC analysis more accessible. 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.

The LCC analysis required by BREEAM has to be carried out based on the proposals developed during concept design and then updated during the developed/technical design.

The LCC analysis required by DGNB, can be used as a target or requirement in the tender phase. The LCC has to be respected as a requirement in the bids. Modifications during construction have to be sufficiently explained i.e. to show that the LCC will not be impacted.

In any case, LCC can be applied in different ways and therefore in different stages during the project, as demonstrated in the Davis Langdon cases.

→ Inventory of lessons learned

The experience with BREEAM highlights a number of attention points. First, at that time, LCC was not a common practice and an optimal Life-Cycle Cost was not the main incentive to steer design improvements.

In fact, a kind of opportunistic approach was identified: the category was selected when there was a relationship with another design aspect. For instance, as the architect and technical engineer explore different design options anyway for the building envelope and technical installations, the additional effort to perform an LCC analysis is limited. LCC analyses on different options for structures are also reported to be relatively easy to conduct, as there are no costs involved regarding maintenance or operation.

A second aspect is the fact that the client will rarely adapt the chosen solution according to the result of the LCC analysis if it does not correspond with the initial design intentions. As a result, the client will often choose not to obtain any credits on the LCC-criterion.

Finally, a split-incentive has been observed: real estate developers will sell the building and as such do not really consider the maintenance costs, while tenants have difficulties judging and evaluating the maintenance costs (in contrast to energy consumption, due to a lack of knowledge of benchmarks and experience).

The DGNB approach is appreciated as it allows comparisons between the LCC-results of projects (whole building, same scope). In addition, the guidelines provide additional support by making cost data figures available that can be used to fill any data gaps.

The LCC analyses conducted in the case studies drew attention to the following learning points:

- Comparability: the need for consistency in assumptions and data entries to enable comparison of 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 the discussion on the level 1 and level 2 calculations;
- Reliability of the benchmarks derived from the LCC-data database: the number and quality of entries in the database will influence the reliability.

A key learning point identified in the Davis Langdon case studies is the fact that the application of the methodology in the case studies suggests that during the 'in use' phase, there appears to be a certain 'optimistic' approach in the way LCC is applied at initial stages of projects that leads to inaccurate assumptions for maintenance and operational costs. This is primarily due to lack of real data from operational assets to input into the LCC calculations but also relates to the way buildings or systems are used in real life.

→ Indicator options

Table 61: 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 | | | |
| 6.1 Life Cycle Costs | | | | | | | |
| Annual costs | Local currency per year normalised per m² floor area | 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 |
| Net present value | Local currency (for instance €, NOK, Kr, £) or normalized per m² floor area | 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 |

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

4.6.2. VALUE

→ Improvement options

IMMO VALUE addresses the gap between the integration of energy efficiency and LCC into valuation practice. It focusses on the development of methodologies where energy efficient buildings would see their energy advantage reflected in the market value. LCC data are an input for the developed methodologies.

The improvement option identified is: impact on the market value as a result of energy performance.

→ Tools, methodologies and standards

The European Valuation Standards (EVS) of The European Group of Valuers' Associations (TEGoVA) and the Sustainability and commercial property valuation guidance of the Royal Institute of Chartered Surveyors (RICS) have been identified as key references concerning valuation.

The IMMOVALUE project is a notable example of an EU project that has sought to develop modified property valuation methodologies. It focussed ~~based~~ on three common approaches to calculate market value (income related, sales comparison and cost approaches). The ~~new~~ modified approaches reflect energy efficiency and LCCA in a more transparent and quantitative way. More recent EU projects such as Renovalue and Revalue have sought to further engage with valuation professionals on how to better reflect improved environmental performance and risk management in valuation processes.

The income related approaches are based on the expectation of future rental income, which implies that these approaches are used for offices or other commercial buildings. The appraiser uses the estimated rental value based on market-data and currently available rental information to determine the gross potential income of the property being valued.

The sales comparison approach is based on the idea that identical houses should have identical prices. It is highly recommended for valuation of condominiums, especially if they are owner-occupied. In the case of single family houses, it is recommended just for typical, standardized objects, such as semi-detached houses. For the valuation of multifamily-houses it should have only a supportive role.

The cost approach uses the replacement costs of the property being valued. In general, the cost approach is used for properties where the costs play the dominant role. This approach is the least frequently used because it is not able to reflect the market in most cases. Nevertheless, many countries still use it as an accepted valuation approach.

The IMMO-VALUE field study developed a scoring model to quantify the degree to which the property market is already influenced by green or energy-efficient buildings: the Weighted Adjustment for Valuation Parameter Effecting Characteristics (WAPEC) tool. The scoring model is a tool to get a feeling about how important energy efficiency is in that particular market. Furthermore the tool helps to quantify the effect. Output of the tool is the Weighted Adjustment Factor (WAF). It is the result of multiplying three adjustment 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.

However, it should be taken into account that the approach developed in IMMOVALUE – an overall adjustment of the preliminary valuation – is understood to be more typically applied in German speaking countries, and is considered to be potentially problematic because it may not allow for individual sustainability factors to be identified/analysed separately for their influence on the valuation¹⁶⁰.

→ Data requirements

IMMO VALUE addresses the gap between the integration of energy efficiency and LCC analysis into valuation practice. It focuses on the development of methodologies where energy efficient buildings would see that advantage reflected in their market value. LCC data are an input for the developed methodologies.

IMMO-value distinguished developed and opaque markets¹⁶¹, depending on the public availability of sales and rental data.

In addition, in order to properly integrate the energy cost saving potential and operating cost saving potential, data on these aspects are required. In the case of IMMO-value, this corresponded with EPC and LCC analysis data. As a result, integrating other sustainability aspects into the valuation requires (public) data availability of these aspects.

There are in practically all cases serious data problems related to the lack of availability of EPC and LCC for the subject and the compared properties. LCC data was sometimes impossible to find because LCC are not usually undertaken in real estate practice. Such analysis tools are too sophisticated and extensive such that their application in property valuation property cannot be claimed. In general, finding reliable and adequate market information regarding buildings' energy efficiency or life-cycle costs is still quite difficult because the market is not transparent enough and valuers have to rely on their own assumptions instead. For developed markets, it is recommended that national property valuation committees and associations who have access to energy efficiency and related data information should provide access to such analytic results for the specific property market and property type.

¹⁶⁰ Lützkendorf.T and Lorenz.D, *Sustainability and property valuation – systematisation of existing approaches and recommendations for future action*, Journal of Property Investment & Finance, Vol 29, No.6, 2011, PP.644-676

¹⁶¹ An opaque market can be a market where all comparatives are non-efficient or a market where sales and rental data is not fully available to the public.

→ Processes and actors

Lead actors are real estate agents and developers. Supporting actors are energy experts, financial consultants or other experts, depending on the sustainability aspects that have to be integrated in the valuation.

The EPC includes a lot of detailed information, therefore it is important that valuers are able to understand and use the right figures. As a result, valuers might require training in order to interpret energy benchmarks, results of LCC and other technical characteristics of the building correctly.

→ Inventory of lessons learned

During recent years the interest of the real estate industry in energy efficiency and other sustainability issues has increased in general. Several recent studies in the US and Europe confirmed a certain willingness to pay for environmental features. However, there is a considerable gap between general acknowledgement of importance and practical integration of energy efficiency and LCC into valuation practice. Practically all valuation reports deal with these issues only in a qualitative way and are not able to reflect the issue in quantitative terms.

In general however, the value impact is limited. Only very energy efficient and sustainable properties result in a premium of 5-10 %. Higher value impacts depend on an increased market sensitivity towards energy efficiency and sustainability (i.e. if the markets do not only account for cost advantages but account also for better comfort levels, for better productivity etc. to be achieved in sustainable buildings).

In valuation practice, the lack of data sets limits for a broad application of the modified valuation approaches. In most cases data on energy efficiency, LCC and other sustainability aspects are very vague. Although mandatory by regulation EPC is still missing for many valuation processes, LCC is practically not available at all. For a broad application valuers need reliable databases on reference buildings (comparables) 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 in order to interpret energy benchmarks, results of LCC analyses and other technical characteristics of the building correctly.

→ Indicator options

Table 62: 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 | | | |
| 6.2 Creating value and managing risk | | | | | | | |
| Market Value (Gross Development Value) | Local currency (e.g. €, SEK) | B1 – B7: Use stage | Concept and detailed design Refurbishment | Building asset | According to chosen valuation method | - | FS CC |
| Value uplift | Local currency (e.g. €) per m ² GFA | B1 – B7: Use stage | | | | - | FS CC |

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

Table 63: Long list of macro-objective 6 supporting 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 | | | |
| 6.2 Creating value and managing risk | | | | | | | |
| Weighted Adjustment Factor (WAF) | %, € | 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)

CHAPTER 5 CROSS-CUTTING FINDINGS

This chapter summarises a number of horizontal findings, cross-cutting among the macro-objectives.

Not all the aspects of the macro-objective can easily be expressed in an indicator on building level. Some aspects are more relevant or practical to assess at the level of a space, building components or even at the building product level.

Examples:

- Ventilation rates or indoor air quality are assessed at room-level;
- LCA and LCC are less complicated when conducted at building component level rather than at building level.

The building practice is more familiar with certain macro-objective aspects than others, due to a wide range of reasons, such as the lack of existing regulation, common methodology or complexity. As a result, indicators for these aspects might need more effort to implement successfully. Aspects identified as state-of-the-art are:

- Embodied carbon emissions (B1);
- Material utility (B2);
- Moisture and Mould (B4);
- Thermal tolerance in a future climate (B5);
- Value (B6).

Geographical location is an important factor to consider, as a certain aspect might be common in some Member States but state-of-the-art in other Member States. For instance, building practices in the UK might be more familiar with thermal comfort simulations using future climate projections than in other regions in Europe. Another example: addressing mould and moisture is common practice in Finland but state-of-the-art in Belgium.

To respond to the European context, a common framework with the ability to adapt to local context factors might be recommended. To give an example: the Color Palette of the Skanska Group, which defines generic ambitions but leaves room for Skanska's Business Units to further specify the performance targets and methodologies based on their local context (B1). However, the EPBD and the national/regional EPBD-regulations both demonstrate the advantages and disadvantages of this approach: despite a European-wide framework, the national approaches differ significantly from each other.

Indicators that are practical to use, should be coupled to existing practices as much as possible, to minimize additional efforts and skills needed to assess these indicators. This can relate both to existing methodologies/tools, or existing regulations and might require targeting specific actors, design phases or building components.

Examples:

- Embodied carbon calculations that are coupled to common contractor tools such as cost estimations, Bill of Materials (BoM) or Building Information Modelling (BIM) (B1);
- Embodied carbon calculations targeted to building structures can be more easily embedded in the practice of the structural engineer (B1);

- Certification schemes link to the existing EBPD regulation for their operational carbon emission targets (B1).

A stepwise approach is identified in a number of field studies. This can be a good approach to introduce “new” indicators in the building practice.

Examples identified:

- In a first step, perform an assessment without quantitative targets. Only in a second step, quantitative targets or benchmarks are defined e.g. carbon footprint calculations in Skanska’s practice;
- Use generic data with the option to apply specific data when available e.g. the level 1 and level 2 LCC databases.

Indicators and associated calculation methodologies can have a wide range in scope, in particular with regards to the life-cycle stages, the building components or use categories considered.

Examples:

- Carbon footprint calculations, LCA or LCC rarely include all life-cycle stages (production, construction, in-use and end-of-life);
- Carbon footprint calculations can be performed on the building structure only, or incorporated into other building components such as facades or technical installations;
- Operational carbon calculations cover energy used for heating, cooling, domestic hot water and auxiliary services but not always energy used for lighting and rarely energy used for processes or electrical applications.

To respond to this, the scope of the indicator could be made more transparent. Another approach could be to compose indicators with a modular nature. The initial scope can be further extended with additional building components or life-cycle stages to be considered.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

In this chapter, key factors are summarized that have to be considered when selecting suitable indicators and specifying accompanying guidelines.

6.1. GREENHOUSE GAS EMISSIONS FROM BUILDING LIFE CYCLE ENERGY USE (MACRO-OBJECTIVE B1)

Carbon emissions, normalized per gross floor area (m²), is an indicator that covers the full scope of this macro-objective. A distinction has to be made between an operational part and embodied part. The sum of operational carbon emissions and embodied carbon emissions is the total carbon emissions or carbon footprint of a building. However, comparability among different regions and Member States requires caution, as scope and assumptions can differ in the case of operational (and likely, also embodied) carbon emissions.

6.1.1. KEY FACTORS TO CONSIDER – OPERATIONAL CARBON EMISSIONS

- The operational part of the carbon emissions is inevitably linked to the regional and national EPBD-regulations. While the EPBD and its recast provides a European framework, calculation methodologies still differ significantly among the different Member States. It is difficult to define a common indicator, as there is a large variation in performance targets, data requirements, scope and boundary conditions. The advantage is that the building practice is very familiar with it;
- Dynamic simulations have the potential to assess operational energy use more accurately than steady-state simulations, but a gap between predicted and actual energy use is still very likely. Furthermore, it has to be taken into account that dynamic simulations are more complex, require more skills and efforts, and can result in additional costs. Therefore, when dynamic simulations are used, it might be necessary to provide specific guidelines to clearly define the assumptions in order to minimize the gap between predicted and actual energy use;
- Solar heat gains are better captured/calculated in dynamic simulations than steady-state simulations and therefore, dynamic simulations are typically used to address thermal comfort and overheating issues;
- Quality assurance tests such as air-tightness tests or thermographic scans are useful to confirm the quality of the construction works. However, depending on the timing of the tests, it might be difficult to steer improvement if needed;
- It has to be taken into account that quality assurance tests are likely to involve a third party and thus imply additional costs. Furthermore, depending on the test, it can sometimes prove difficult to execute valid practical tests due to measurement error or other issues such as weather conditions;
- There is an important cross-link with thermal comfort and with MO B4a “Healthy and comfortable spaces”, in particular an appropriate ventilation strategy, which is inevitably linked with the air-tightness level of the building envelope.

6.1.2. KEY FACTORS TO CONSIDER – EMBODIED CARBON EMISSIONS

- There seem to be no commonly accepted benchmark values that can function as absolute performance target values;
- The scope and assumptions used for the embodied carbon calculations differ significantly, in particular concerning the life cycle stages (production, construction, use and end of life) and the building components (structure, facades, technical installations) to consider;
- The availability of consistent, reliable and accurate databases with emission data on national (or regional) level are identified as a barrier. In addition, as there is a lack of common guidelines, databases use different assumptions and hinder comparability of results. This points out the need for a common methodology on European level but with (open-source) databases on regional or local level;
- Material quantities are typically obtained from cost estimations, bill of materials and BIM-models. Quality assurance and data verification are highlighted as a point of attention;
- Current building practice is not very familiar with embodied carbon assessments as it is not widely applied yet. However, there is a potential to embed carbon footprinting in the existing practice of existing actors, more in particular the (main) contractor or structural engineer;
- Initially focusing on the building's structure could be a way forward, as the structure causes a significant contribution to the building's carbon emissions¹⁶²; building materials used are conventional materials and as such, data availability is less of an issue; and it relates directly to the practice of certain building actors i.e. the structural engineer and the contractor. This initial scope can be expanded, for instance with additional specifications for certain building components (e.g. façade elements or wooden structures).

6.2. RESOURCE EFFICIENT MATERIAL LIFE CYCLES (MACRO-OBJECTIVE B2)

It is not possible to define an indicator on the level of the macro-objective. Indicators for B2 should be defined for its sub-aspects.

6.2.1. KEY FACTORS TO CONSIDER – CIRCULAR FLOWS

- Recovery ratio by weight can be a useful indicator. The difficulty to reach recovery ratio targets depends on the country context. In fact, the analysis of the field studies identified that conditions for C&D waste management vary significantly among Member States. Market and policy factors have a large impact, for instance in providing financial incentives and to set a proper construction culture/context;
- Another option is to not only focus on material streams but on the reuse of whole buildings, or major elements such as structures and foundations;
- Construction waste is easier to recover/recycle/reuse than demolition waste (e.g. bricks). Construction waste is less mixed than demolition waste because pure fractions can be obtained during construction;
- As already pointed-out, it does not address the type of recovery and the quality of the recovered material. In addition, it only addresses to a certain extent the minimization of

¹⁶² De Wolf, C., 2014, *Material quantities in building structures and their environmental impact*, Massachusetts Institute of Technology, p. 10

waste. As a result, an indicator on mass arisings can be explored further as it was not fully covered in the analysed field studies;

- Recovery ratios do not provide information about the type of recovery (reuse, recycling, energy recovery). Furthermore, recovery ratios don't necessarily reflect the quality of the produced material streams. In order to achieve high-grade recycled material, the amount of unwanted constituents in material streams needs to be limited. This can be achieved by a selective demolition process. If no selective demolition was conducted, mixed material fractions might have to be sorted out, either manually, which can be time-consuming, or by using advanced sorting techniques to obtain high-quality material fractions;
- The selective disposal of non-recyclable hazardous waste is crucial for a viable circular economy. Purer waste streams with a low environmental risk clearly have a greater upcycling potential. Non-recyclable hazardous waste could be excluded from the recovery ratios;
- Finally, the amount of recycled material in a new product as an indicator certainly has its merits. However, recycled content does not provide information on the quality of the end-product (durability) or the efficiency/quality of the recycling process (for instance, if the end-product was the result of "upcycling" or "downcycling"; a recycled product that would be recycled anyway versus a recycled product that would normally be disposed). The impact of a replacement with recyclable materials on sustainability depends on several factors (e.g. primary material that is replaced, type of recycled material, transport distances). To include these factors, LCA studies are necessary.

6.2.2. KEY FACTORS TO CONSIDER – MATERIAL UTILITY

Future adaptation potential

- Whilst the potential for future adaptability of buildings is highlighted in literature as being an important consideration, there are no mature indicators currently in use;
- From a standardisation perspective, EN 15643-3/EN 16309 provides some limited pointers as to measures to increase adaptability. ISO 20887 Design for Disassembly and Adaptability of Buildings is under development by TC 59/SC17;
- A composite score can be derived, for instance based on a checklist as included in the DGNB-scheme, which could form the basis for an indicator for office buildings;
- Increasing the future adaptation potential of the building has to be addressed early in the design process. The architect and structural engineer hence play a key role. Guidelines and recommendations that specifically address the design process have a large potential to steer improvement in this aspect.

Disassembly potential

- A greater consideration at design and construction stage of the building's end of life (ease of dismantling/separability of building elements are cited) should be primary considerations for design teams and clients;
- The state of the art is a category scoring for ease of disassembly, scope of disassembly and viability of disassembly (DGNB). This could form the basis for an indicator, with the scope defined in order to focus attention on hotspot building elements;
- A strong relationship is identified with MO B6 "life cycle cost and value", more in particular the design life and/or service life for a building, elements and components are considered in a number of certification schemes.

6.2.3. KEY FACTORS TO CONSIDER – ENVIRONMENTAL IMPACT

- The main methodology applied is Life Cycle Assessment (LCA) according to LCA standards such as ISO 14040-14043, EN 15978, EN 15804 and ISO 21930;
- In practice, LCA is commonly applied on building component level to compare different design or construction options. LCA on building level is less common, although certification schemes are evolving towards this approach in recent versions;
- Simplified LCA-tools such as BREEAM's Green Guide and HQE's Elodie, but also certification (e.g. FSC-labels) and classification systems (e.g. NIBE) are reported to be user-friendly and more easy to use in early design stages. However, assumptions in the tool or methodology (for instance regarding life cycle stages and environmental impact considered, or databases used) are not always transparent or clear (e.g. Green Guide which has a "black-box" approach);
- A key discussion point is whether to use a set of individual (impact) indicators (for instance, the seven impact categories defined by CEN TC350), or to use an aggregated/weighted (set of) indicator(s);
- Using a set of individual indicators makes it difficult to compare two or more building or building element alternatives. Hence, decision-making based on an (independent) set of individual life cycle impact indicators is not practical. This is true for designers, building clients, but also for policy actors. Option 1 is used for 'hot-spot analysis';
- Using an aggregated indicator (a single indicator covering ALL individual impact categories, after a normalization step and weighting) is a practical solution for comparisons and decision-making (based on comparisons), but is further away from the real environmental mechanism. Furthermore, there is no consensus on a 'universally accepted weighting scheme';
- It is recommended to align the development of Core Indicators with the CEN TC350 and/or PEF activities;
- There is a strong relationship with B1 embodied carbon, as Global Warming Potential is one of the impact categories that is assessed in LCA.

6.3. WATER USE (MACRO-OBJECTIVE B3)

6.3.1. KEY FACTORS TO CONSIDER

- A clear distinction can be made between office and residential projects. A key difference is the fact that performance targets for water consumption are defined on the level of the building (normalized per person) in case of office projects and on the level of the sanitary appliances (as a target flow rate) in case of residential buildings;
- Design assumptions and threshold values of flow rates for sanitary appliances vary per certification scheme. The LEED certification scheme was reported to have the most stringent criteria;
- There is no key standard identified. A number of tools to calculate the water consumption during a building's use have been identified in the certification schemes. The main differences are: the level of transparency of the tool, input parameters required, and water use considered (both on the "demand side" (i.e. non-potable water use such as cleaning or irrigation) as the "supply side" (i.e. rainwater harvesting, grey water reuse). For these reasons, the approach of DGNB seems to be the most complete;

- Regarding water demand strategies, more in particular rainwater harvesting and grey water reuse, it is noted that regional or national regulation can have an important influence.

6.4. HEALTHY AND COMFORTABLE SPACES (MACRO-OBJECTIVE B4A)

The analysed field studies indicate a strong relationship between a building's ventilation strategy, the exposure to hazardous substances from building product emissions and exposure to hazardous substances from outdoor air sources. Hence it seems appropriate to use a holistic approach instead of focussing on these aspects separately. Reference is made to EnVIE¹⁶³ and HealthVent initiatives, which put forward a framework based on the following three principles:

- Limit entrance of pollutants from outdoor;
- Limit pollutants from indoor sources by choosing low emission cleaning products, building materials and furniture;
- Limit exposure by using a ventilation strategy based on health criteria.

6.4.1. KEY FACTORS TO CONSIDER –VENTILATION STRATEGY AND VENTILATION INTAKE AIR

- Concerning the exposure to hazardous substances resulting from the ventilation intake air, a distinction can be made between improvement options that target specifically hazardous substances as the result of the intake (of outdoor) air and improvement options that focus on the performance of the ventilation system;
- Regarding the first point, in a number of field studies (especially the office projects), criteria are put forward to limit the intake of outdoor pollutants, either qualitatively by specifying requirements for the location and distance of air intake and exhaust openings or quantitatively by specifying filter class requirements;
- European standard EN 15251 offers several options, such as based on CO₂-level or a design ventilation rate that takes into consideration both the ventilation rate per person (i.e. occupants as the main source of pollution) and per square meter floor area (i.e. pollutions from material emissions);
- Performance targets for ventilation flow rates are defined on room-level, rather than on building level;
- A distinction can be made between residential and non-residential buildings. This results in other performance targets and approaches;
- There is a strong relationship between the ventilation strategy and energy performance, as already indicated previously.

6.4.2. KEY FACTORS TO CONSIDER –MATERIAL EMISSIONS

- The determination of the concentration levels of hazardous substances can be performed using different analytical methods and techniques, and can be expressed in various units. The ISO-16000 is identified as key standard in this regards. A clear distinction can be made between approaches which imply product emission testing and approaches which focus on in-situ air measurements;
- In the case of product emission testing, the scope of the assessment of hazardous substances is largely focused on VOCs and formaldehyde. This initial scope can be enlarged

¹⁶³ EnVIE (2009) *Objectives and approach of EnVIE* [online], available at: <http://paginas.fe.up.pt/~envie/> [20/5/2016]

for certain product groups. In general, building aspects considered include the building materials related to interior floor finishings, wall or ceiling coverings. Assets such as furniture and cleaning products, which are closely related to user behavior, are typically not considered, although the results of emission tests of a typical office setting in the Officair field study indicated;

- In the case of in-situ air measurements, it is observed that the scope of the assessment of hazardous substances is broader. In addition to formaldehyde and VOCs, the following pollutants are included in the assessment of at least one field study: CO, CO₂, NO₂, O₃, particulate matter (PM_{2.5}, PM_x and PM₁₀) and Radon. Furthermore, the total VOC-level (TVOC) can be calculated as well;
- Timing (winter or summer) and location of the in-situ measurements (i.e. the room or space to conduct the measurements) can have a significant influence on the results. There is also a link between the timing and the scope of the assessment (e.g. pre- or post-occupation, depending on the fact if only interior is considered or user behaviour as well);
- In-situ air measurements have to be seen as quality assurance;
- It is difficult to identify the approach which is best in terms of minimising risk of exposure. The majority of criteria of the certification schemes target indoor finishings, but there is not a clearly defined priority list. This should clearly relate to the goal of the assessment: does the assessment target the building, the interior or the equipment? The field studies indicate a strong relationship between the building/equipment aspects that are considered, the assessment method and the scope of the hazardous substances;
- It is difficult to capture the influence of user behaviour and context factors (for instance the location of the building and possible external pollution related to it).

6.4.3. KEY FACTORS TO CONSIDER – MOISTURE AND MOULD

- Measurement of damp and mould is a relatively new area, and it appears that test methods to evaluate levels in-situ are relatively undeveloped for widespread use;
- Qualitative methods to assess moisture and mould issues have been identified, such as a survey targeted at building managers or occupants, and a walkthrough with check-list for a detailed inspection of trained experts;
- Quantitative methods that have been identified concern air and surface sampling by accredited third parties. ISO 21527-1 and ISO 4833 are found to be the key standards for the analysis of fungi and bacteria respectively;
- The field studies indicated a number of national standards that put forward performance target values for concentrations of bacteria and fungi, such as the French standard XP X 43-401 or the Flemish Indoor Environment Decree of 11/6/2014. Further investigation is needed to identify other international and national benchmark values;
- Similar to in-situ measurements for chemical substances, the timing and location of the in-situ measurements is very important in case of biological agents as well;
- While the field studies analysed did not elaborate in detail on addressing moisture and mould issues during design stage and maintenance, they are understood to be crucial project phases to prevent or remediate moisture and mould problems.

6.5. RESILIENCE TO CLIMATE CHANGE (MACRO-OBJECTIVE B5)

6.5.1. KEY FACTORS TO CONSIDER – THERMAL TOLERANCES

- There is a very strong link with thermal comfort. Hence, the tools, methodologies and indicators are similar to the ones typically used for thermal comfort. The main difference is the use of weather data sets to simulate future scenarios (e.g. 2030, 2050 or 2080);
- There is a large dependency on availability of this future climate data. It has to be further investigated to which extent future climate data, comparable to the UKCP09 and CIBSE data-sets in the UK, is also available for other European regions;
- An alternative could be to use historic weather data to represent future conditions (as was the case in the Knowledge for Climate field study). However, the probabilistic approach of the UKCP09 and CIBSE data series are likely to provide a more stable and reliable basis for the simulations;
- Simulation software used are dynamic simulation tools (e.g. EnergyPlus). In other words, tools that can use alternative weather files for the calculations. It has to be examined further to which extent steady-state simulation tools can use projected climate data when assessing thermal comfort. It is assumed that this will not cause any issues;
- Two approaches are used regarding thermal comfort: static approach and adaptive approach. The importance of implementing adaptive thermal comfort models, especially in large scale office buildings, are highlighted in climate change impact case studies. Adaptive thermal comfort can be exploited by designers to make buildings more resilient towards climate change by providing opportunities for occupants to make adjustments of their behaviors to suit the changing environment;
- The level of thermal comfort in office buildings differs from the level of thermal comfort that people experience in their homes. This is caused by several factors. Residents have different activity levels than occupants in office building and the activity level can more easily be adapted to the situation.

6.5.2. KEY FACTORS TO CONSIDER – GREEN INFRASTRUCTURES

- The BAF, GSF and the green point system are useful to indicate the quantity of greenery and to a certain extent the quality of greenery (by making use of weighting factors);
- They can incentivize building clients, local authorities and/or property developers to implement measures that will have an influence on the future microclimate on the individual building/site;
- None of these indicators really capture the specific impact of “green” measures to the energy consumption or thermal comfort of the building. In order to be able to calculate this, other tools or methodologies are likely required, such as dynamic simulations.

6.6. OPTIMISED LIFE CYCLE COST AND VALUE (MACRO-OBJECTIVE B6)

6.6.1. KEY FACTORS TO CONSIDER – LIFE CYCLE COST

- ISO 15686-5 seems to be the key standard, as it is referenced in all field studies analysed;
- LCC can be conducted on building component level (e.g. BREEAM) or on building level (e.g. DGNB);

- The DGNB-certification scheme includes benchmark values for LCC of non-residential buildings;
- There is a need for consistency in assumptions and data entries to enable comparison of scenarios and building projects;
- The desired end-use for the LCC calculation results determine the level of accuracy of the data. Based on the experience of the field studies, the main data gap seems to be cost data related to operation and maintenance;
- LCC analysis is reported to be often too time-demanding or too complex for building actors. The two-step approach developed as part of LCC-data, aims at overcoming this barrier and making LCC analysis more accessible.

6.6.2. KEY FACTORS TO CONSIDER – VALUE

- The European Valuation Standards (EVS) of the The European Group of Valuers' Associations (TEGoVA) and the Sustainability and commercial property valuation guidance of the Royal Institute of Chartered Surveyors (RICS) have been identified as key references concerning valuation;
- The IMMOVALUE project is a notable example of an EU project that has sought to develop developed modified property valuation methodologies. It focussed based on three common approaches to calculate market value (income related, sales comparison and cost approaches). The new modified approaches reflect energy efficiency and LCCA in a more transparent and quantitative way. More recent EU projects such as Renovalue and Revalue have sought to further engage with valuation professionals on how to better reflect improved environmental performance and risk management in valuation processes;
- In valuation practice, the lack of data sets limits for a broad application of the modified valuation approaches. In most cases data on energy efficiency, LCC and other sustainability aspects are very vague. Valuers might need support to make them capable to interpret energy benchmarks, results of LCC analyses and other technical characteristics of the building in a correct way;
- For a broad application valuers need reliable databases on reference buildings (comparables) including not only data on building site, rent level and building equipment but also on energy efficiency and various operational cost categories.

REFERENCES

[EC, 2014]

European Commission. (2014) *Communication on Resource Efficiency Opportunities in the Green Building Sector (COM (2014) 445)*. Brussels: European Commission.

[JRC, 2015]

Dodd, N., Donatello, S., Garbarino, E., Gama-Caldas, M. (2015). *Identifying macro-objectives for the life cycle environmental performance and resource efficiency of EU buildings – working paper 1*. Sevilla: JRC Directorate B Unit 5.

[JRC, 2016]

Dodd, N., Donatello, S., Gama-Caldas, M., Van de Vyver, I., Debacker, W., Stranger, M., Spirinckx, C., Dugrosprez, O. (2016). *Identifying indicators for the life cycle environmental performance, quality and value of EU office and residential buildings – Draft working paper 2*. Sevilla: JRC Directorate B Unit 5

[REB, 2015]

JRC-IPTS. (2015). *Resource Efficient Buildings – Development of a framework of core indicators for the assessment of environmental performance of buildings: project overview*.

[VITO, 2015]

VITO, ALTO, KUL. (2015): Analysis of field studies to support the identification of options for building resource efficiency performance indicators: Inception report. Mol, Belgium: Flemish Institute for Technological Research (VITO)

[VITO, 2016]

VITO, ALTO, KUL. (2015): Analysis of field studies to support the identification of options for building resource efficiency performance indicators: Progress report. Mol, Belgium: Flemish Institute for Technological Research (VITO)

[VITO, 2016]

VITO, ARUP. (2016). *Study on differences in design and actual environmental performance of buildings (GAPS-study)*. Mol: Flemish Institute for Technological Research (VITO)

ANNEX 1 CATALOGUE OF FIELD STUDIES

ANNEX 2 CROSS-CHECKS
