Technische Universität München
Fakultät für Architektur

ISBN 978-3-941370-50-0

smartTES

Innovation in timber construction for the modernisation of the building envelope

Book 6
TES sustainability

Simon le Roux
Aalto University School of Arts, Design and Architecture

Stephan Ott
TUM Technische Universität München

10.03.2014

Acknowledgements

“smartTES – Innovation in timber construction for the building modernization” is a transnational research project under coordination of the WoodWisdom-Net and funding distributed by national funding agencies.
Duration 2010-2013

Partners
Germany
- Technische Universität München,
  Lehrstuhl für Holzbau und Baukonstruktion, Prof. Dr.-Ing. Stefan Winter
  Fachgebiet Holzbau, Prof. Hermann Kaufmann
- Hochschule Rosenheim
- B&O Wohnungswirtschaft
- Gumpp & Maier GmbH
- Ambros GmbH
- Funding: BMBF

Finland
- Aalto University
- Finnish Real Estate Federation (Suomen Kiinteistöliitto ry)
- Finnish Wood Research Oy
- Metsä Wood
- Puuinfo Oy
- PAK RAK Oy
- Funding: TEKES

Norway
- SINTEF
- NTNU Norwegian University of Science and Technology
- Funding: The Research Council of Norway

Project coordination: Dipl.-Ing. Frank Lattke

www.tesenergyfacade.com

Publisher
Technische Universität München
Fakultät für Architektur
Arcisstr. 21, 80333 München
www.ar.tum.de, verlag@ar.tum.de

ISBN 978-3-941370-50-0

Public funding by

SPONSORED BY THE
Federal Ministry of Education and Research

Tekes

The Research Council of Norway

Content

Summary

Section 1 strategic goals for evaluating TES

On the strategic level of sustainability, the TES methodology of refurbishment for residential buildings has been analysed and compared against benchmarks for sustainable construction: international standards for core performance indicators (ISO), the European framework for sustainability in the construction industry (CEN), and against advanced and pragmatic sustainability rating tools used in Europe. Life Cycle Assessment (LCA) standards and tools are available in the building construction industry and improving in usability, and the demand for LCA is growing on both building and product level due to new product regulations (EPD) and demand for certified projects.

A range of assessment approaches are available for the quantification of energy efficiency targets and for the comparison of improvements in energy performance, and for criteria to advance construction quality. BREEAM as an example of a rating system is more prescriptive and arguably low-tech, based on experience with the construction industry; DGNB as an example is more technically advanced and demanding for technical processes and construction data, based on a broad and progressive LCA approach to embodied and operational impacts.

The use TES for refurbishment has been shown to support the preconditions to achieve good environmental ratings, improved energy performance, and reduce life cycle impacts, with robust low-tech measures, observing detailed prescriptive criteria, and also analysed with advanced LCA methodology. It is feasible and recommended to include a broad range of sustainability targets into a refurbishment project, and enhance the overall performance with project management, and with a bottom-up approach to end-user and stakeholder needs, and the application of specific tangible measures. The broader holistic view enables upfront integrated design to deliver a fit-for-use building, with durable environmental, economical, technical, social, functional and process quality.

Section 2 integration of TES into the life cycle of refurbishment projects

The TES energy facade is applied to buildings in order to improve the overall energy performance, and to improve the quality of life in the building as a whole. The refurbishment process of an entire building, or the process of retrofitting an energy facade onto the exterior of the building, has impacts during the construction phase of a renovation project. It has been a goal of the smartTES sustainability research to identify measure with which the environmental impacts of the construction phase may be reduced, to improve the process of a refurbishment, and support the broader objectives of construction quality and sustainability. Therefore standards for LCA and the sustainability assessment of the refurbishment project takes the building as a whole into consideration for integrated design, for building level LCA methodology, and for improved process quality.

The goal to develop multifunctional TES facades and to add value to the prefabrication of TES components is conditional upon integrated design and procurement, which place emphasis on life cycle quality and durable functional quality. TES is shown as a robust solution to overcoming the serious challenges of built obsolescence.

The research has studied three cases, in which the material flow associated with the construction phase has been quantified, in order to compare the burdens from the output waste of partial demolition and the input of new materials against the benefits of retaining and reusing existing structures and the recycling of those demolition materials recovered from landfill. The operational benefit gained from prolonging the service life of the existing building, with improved energy efficiency, updated fitness for use and upgraded user comfort can only partially be quantified, and is subject to multicriteria assessment with a variety of localised stakeholder priorities.

Section 3 TES on the level of environmental product declarations

TES energy facade as a concept is based on a robust method to reduce the heating energy demand of an existing building. The goal is to reduce the carbon footprint associated with the operation of a building, in a way that minimises the embodied carbon footprint associated with the manufacturing of materials employed for the facade.

Research has been made in smartTES sustainability to quantify the embodied impacts of the energy facade with standardised rules and methodology for environmental system declarations, in order to calculate and compare the embodied energy, global warming potential and mass of the construction layers and products used for nine different TES cases from Germany, Norway and Finland.

While the core of the TES facade demonstrates low environmental impacts, the choice of facade cladding and individual material layers has a significant effect on the overall environmental impact of the TES manufacturing process, which is only offset after an extended period of reduced operational impacts. The certainty and immediacy of manufacturing and the opportunity to take legal responsibility for construction process impacts places them in a position of critical importance, in comparison to the uncertainties associated with environmental impacts of future energy demands.

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Figure List

Table List

Abbreviations and Units

Abbreviations

AN	Heated space area
BNB	Bewertungssystem Nachhaltiges Bauen für Bundesgebäude (Assessment System Sustainable Construction for Federal Government Buildings) Germany
BREEAM	Building Research Establishment Environmental Assessment Method, UK
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Society for Sustainable Construction)
Ee	Energy efficiency (conservation of energy)
EoL	End of Life
EPD	Environmental Product Declaration
HT’	Specific heat transmission loss
HV	Ventilation loss
HVAC	Heating Ventilation Air Conditioning
IAQ	Indoor Air Quality
ITC	Information Technology and Communication
PEnr	Primary energy content not renewable
PEre	Primary energy content renewable
Qe’	Specific end / use energy demand
Qh’	Specific heat energy demand
Qp’’	Annual primary energy demand
Re	Resource efficiency (conservation of material)
TES	TES EnergyFaçade - timber based element system for improving the energy efficiency of the building envelope
smartTES	Innovation in timber construction for the modernisation of the building envelope
WLC	Whole Life Cost

Units

A_N	[m^2]
PEI_{nr}	[MJ]
PEI_{re}	[MJ]
EPD	Environmental Product Declaration
H_T’	[W/m^2·K]
H_V	[W/K]
Q_h’	[kWh/m^2·a]
Q_e’	[kWh/m^2·a]
Q_p’’	[kWh/a]

Introduction to smartTES Sustainability

TES (Timber based Element System) is targeted at the refurbishment of the European building stock from 1950's to 1980's. The TES sustainability goals are primarily concerned with a holistic approach to energy efficient building refurbishments including TES facade retrofits, employing well managed and cost effective prefabrication methods, and with the ultimate goal to reduce primary energy demand for the operation of a building with the responsible and economical management of resources. Large volumes of material flows result in environmental problems, and TES aims to reduce its' associated environmental impacts.

The European construction industry is moving towards the use of standardised environmental product declarations with the aim to quantify and calculate environmental impacts of construction processes, and thereby provide the information required to compare and evaluate impacts against industry benchmarks for core performance indicators, set limits to impacts, and ultimately make it possible to reduce the environmental burden of buildings, including their refurbishment. The construction industry is increasingly compelled to implement the efficient use, reuse and recycling of materials, by legislation for sustainable resource management, by requirements for material waste reduction and formats for systematic communication and demands for the tracing of raw material sources.

Refurbishment in general is a complex interrelationship between new and old. Sustainability standards, environmental assessments and rating systems are typically intended for new construction projects, whereas the assessment of refurbishment has its own particular set of problems, which are distinguished from new building in the scope of work and in the relative quantification of impacts.

Standardised Life Cycle Assessment (LCA) is becoming a mainstream tool for the quantification of material related environmental impacts of buildings. European and International standards allow for the definition of compliant methods for the life cycle assessment of buildings and define standardised scopes and formats for the declaration of building product environmental impacts (EPD). However, standards do not themselves establish the benchmarks for the comparison and evaluation of the environmental impacts of buildings and their refurbishments. The comparison needs to be made in the industry itself, when the standards definitions are in place and the comparisons needs to be temporal, taking into consideration the continuous evolution of the construction industry, and the economy and society in which it operates.

Within the life of a building, refurbishment is only one phase, and the scope of refurbishment varies significantly. The standardised scope of LCA for refurbishment (EN 15978) covers only the production and transportation of new components; the construction and waste management of the refurbishment process; and the end of life stage of replaced building components. This does not directly take into consideration the overall environmental impact of the existing building, which will have to be assessed in itself before and after refurbishment. As a consequence, the necessary scope and complexity of assessment grows to take into account the interrelation of the old, refurbished and new parts.

Methodology for environmental assessment aims to collect and establish benchmarks for the comparison of the material embodied impacts at building level, and to promote the use of robust life cycle assessment (LCA) tools, and to promote the development of product specific Environmental Product Declarations (EPD).

In environmental assessment methods which are aimed at assisting the design process for building refurbishment, the approach has been to simplify and approximate the assessment of material impacts, and limit the scope of assessment while keeping specific refurbishment targets in focus. This can be done by using generic data for a limited number of building elements which have arguably the most significant environmental impact and potential benefit (i.e. the building thermal envelope). This prescriptive approach may not be the most scientifically rigorous, but the aim is to support the application of best energy efficiency practice in mainstream.

There are two approaches for TES material impact assessment: a prescriptive goal to improve thermal performance up to current best practice level (such as an appropriate passive house definition) while reducing the embodied material environmental impacts to the minimum; OR a comprehensive and scientific goal to undertake full standardised LCA of the refurbishment project using generic, average or specific EPD data, and quantify the refurbishment LCA within the overall life cycle of the building. To date, there is no standard for the evaluation of refurbishment LCA results on the building level. Major refurbishment is a fundamental remodelling of the building envelope, structure and renewal of key building services which materially impact on the performance of the building.

In the foreseeable future, full standardised LCA of TES refurbished buildings, using best practice LCA tools, and TES specific standardised EPD cradle-to-grave data, will establish a credible and solid benchmark for the environmental performance of TES. To date, this goal has not yet been met, but the path forward is outlined.

The smartTES Sustainability work required mainly secondary desk research, based on the young theory of sustainability. The application of sustainability in the field of construction is defined in a generic framework. The work focused on the fundamentals for a refurbishment with TES elements which follows the basic principles of the TES EnergyFaçade method. The framework was prepared with a theoretical background and new but established standards, e.g. [4]. One comes up against the limits of practical experience, available case studies, reliable data and available or even reliable methods for sustainable refurbishment of existing buildings. Therefore it is necessary to conduct on-going field research on basis of the available data from different demonstration projects.

- **Section 1 (smartTES Task 5.1)** deals with the strategic goals for evaluating TES.
- **Section 2 (smartTES Task 5.2)** considers the integration of TES into the life cycles of refurbishment projects
- **Section 3 (smartTES Task 5.1)** examines smartTES on the level of environmental product declarations.

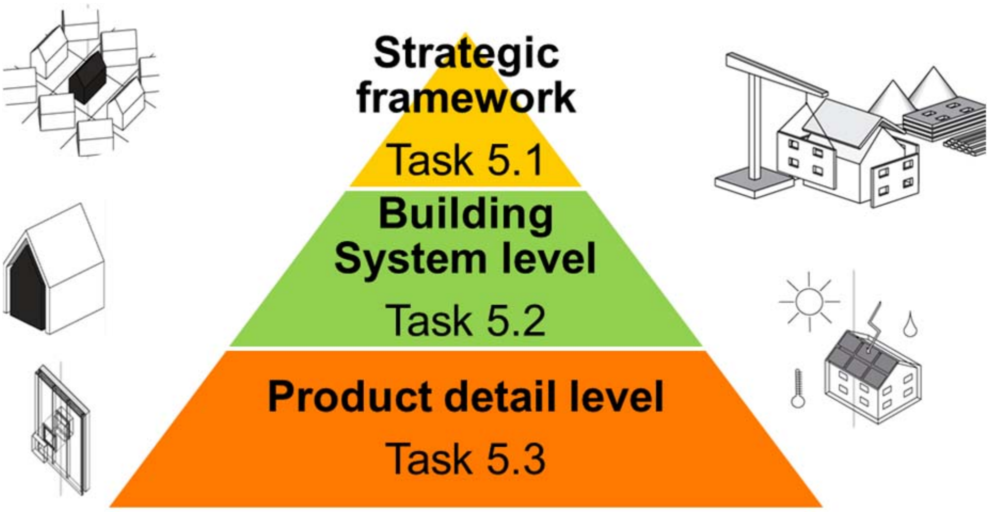

Figure 1-1 Hierarchical division of smartTES sustainability

1. Sustainability criteria and assessment guidelines

Simon le Roux
Aalto University School of Arts, Design and Architecture

1 Sustainability Criteria and assessment guidelines

1.1 Introduction

smartTES sustainability goals and targets are as follows:

- Meet real needs and create enduring value with responsible management
- Define sustainable construction processes for feasible refurbishment
- Reduce the environmental impact of the use and refurbishment of buildings
- Understand the needs of end-user, in order to achieve social quality
- Differentiate TES from standard practice

1.2 Sustainability concept and framework

1.2.1 ISO International standards for sustainable building

The International Organization for Standardization (ISO) introduced an internationally recognized standard for principles for sustainability in buildings and other construction works, *ISO 15392:2008 - Sustainability in building construction – General principles*. The ISO standard is based on the concept of sustainable development, and forms the basis for suites of standards intended to address more specific issues and aspects of sustainability. International ISO standards - and CEN European standards - are applicable to construction works individually and collectively, as well as to building materials, products, services and processes. The concept of sustainable development applies to buildings from their inception to the end of life, understood as their “life cycle”. The construction sector is a key sector in national economies, and the built environment is a major element in determining quality of life, as well as contributing to cultural identity and heritage. Addressing sustainability in building and construction includes the interpretation and consideration of sustainable development in terms of its three aspects - economic, environmental, and social - while meeting the requirements for technical and functional performance. While the challenge of sustainable development is global, the strategies for addressing sustainability in building construction are essentially local and differ in context and content from region to region. Sustainability strategies reflect the context, the preconditions and the priorities and needs, not only in the built and natural environment, but also in the social environment. This social environment includes social equity, culture, traditions, heritage, health and comfort, social infrastructure and safe and healthy environments; and, particularly in developing countries, poverty reduction and job creation. [Source: International Organization for Standardization (ISO), June 2, 2008, Published by IHS]

1.2.2 CEN350 European Standard family

The European Committee for Standardization (CEN)/TC 350 “Sustainability of construction works” suite of standards are intended to assess the sustainability of construction works.

Since 2004 the European Committee for Standardization (CEN) has developed horizontal standardised methods for the assessment of the integrated environmental performance of buildings. Horizontal standardization deals with fundamental principles, concepts, and terminology or technical characteristics, relevant to a number of CEN technical committees and of crucial importance to ensure the coherence of the body of standardization documents.

The Sustainability General Framework is set out in **EN 15643**, which defines the scope of the assessment of the building: The objectives of assessments are to determine the impacts and aspects of the building and its site, to enable the client, user and designer to make decisions and choices that will help to address the need for sustainability of buildings. The European **CEN/TC 350** standards follow definitions of sustainability as set of by international standards.

According to the general principles of sustainability in building construction described in ISO 15392:2008, all three dimensions of sustainability of buildings (environmental, social and economic) are all necessary elements in a systemic approach. Statements on the sustainability performance of a building shall address all three dimensions. This implies that when dealing with the sustainability assessment of a building all three dimensions of sustainability shall be included in an assessment of the building's performance, and communication shall be made accordingly.

The main standards of CEN/TC350 provide a horizontal methodology and standardized quantitative environmental indicators:

- EN 15643-2 Sustainability of construction works – Assessment of buildings - Part 2: Framework for the assessment of environmental performance;
- EN 15978; Sustainability of construction works – Assessment of environmental performance of buildings - Calculation method;
- EN 15804 Sustainability of construction works – Environmental product declarations - Core rules for the product category of construction products.

In January 2012, CEN Technical Committee CEN/TC 350 finalised EN 15804 'Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products' as well as EN 15978 "*Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method*" which governs the scope and the requirements for the application of EPD in Building Assessment.[1]

The main principle of CEN 350 standards is that the performance of construction products must be assessed at building level over the whole life cycle and must take into account the three pillars of sustainability. The intention of horizontal standardization is to avoid direct comparison of building products, and define the performance of the construction product within the life-cycle of the building. The standardization sets core rules for the preparation and communication of Environmental Product Declarations (EPD) for construction products, so that the results and comparisons of building assessments are useful.

According to the methodology of CEN/TC 350, the clients brief and the authorities regulations set the initial requirements for a building (technical and functional requirements, and requirements for environmental, social and economic performance). Based on these requirements, the building's environmental, social and economic performance can be assessed with standardised calculation methodology (EN 15978), which meets the framework for sustainability (EN 15643). The technical information which is required for building assessment is communicated in standardised EPD format. EPD are themselves prepared according to the core product category rules for all construction products and services, as established in EN 15804 (product level of CEN/TC 350 "Sustainability of construction works"). EPD rules specifically for wood and wood-based products are provided in European Standard EN 16485.

Therefore, the functional unit of European Standard sustainability assessment is the building, and the building is assessed according to Life Cycle Assessment. This avoids the direct comparison of building products, and insists that construction products are "intermediary products, which must be evaluated holistically and integrated with the building as a whole, and not just from raw materials until delivery of products (cradle-to-gate).

1.2.3 **Standard development for Life Cycle Assessment**

European Standard EN 15978 sets out a standardised calculation method for the assessment of environmental performance of buildings. The assessment method for the quantitative evaluation of the environmental performance of the building is based on a life cycle approach (LCA).

Of particular interest to TES, EN 15978 defines the LCA boundary for refurbishment of a building including: production and transportation of the new building components; construction and waste management of the refurbishment process; and the end of life stage of replaced building components.

In order to undertake Life Cycle Assessment at building level as described by EN 15978, the LCA requires information from products and services (EN 15804). The assessment covers all stages of the building life cycle and is based on data obtained from EPDs, their "information modules" (prEN 15804) and other information necessary and relevant for carrying out the assessment. The assessment includes all building-related construction products, processes and services, used over the life cycle of the building. The interpretation and value judgments of the results of the assessment are not within the scope of this standard.

In practice, the LCA is based on a Building Information Model (BIM) to enable the quantification of the mass and energy flows. The modelled constituent parts include all building elements such as TES elements, building components such as windows, building products, and building materials; and includes processes related to the building, such as transport, construction, maintenance, repair, replacement, end-of-life processes; and includes the operational use of the building (energy, water). The choice of the level of details depends on the goal and scope of the assessment and of the availability of data at the time the assessment is carried out (sketch plan, design, procurement and handover). The building information - whether it is detailed or aggregated - can be generic, averaged or specific. The building information may be represented in many alternative ways:

- **Generic data** for typical structures and materials used in the building;
- **Average data** combined from different manufacturers or production of the same product;
- **Collective data** to allow an EPD to be established for similar products;
- **Additional information** that is specific to the components and products used in the construction;
- **Specific detailed information** (i.e. a full bill of quantities, dimensions, etc.) for the actual products and components used and directly measured information for utilities and services (energy, water demand, waste, etc.) as built and operated.

When all materials in a building, the relationships between them, varying quantities, different service lives, etc., are taken into account, assessing embodied impacts can be a complex and time-consuming task. With the increasing use of information modelling for construction, the environmental attributes of materials, as used for standardised EPD’s, are now possible to include into the digital description of a building, and BIM tools are available to assess the embodied environmental impact of the building itself. Embodied carbon is the best known embodied impact indicator. With the wider use of BIM it is now viable to produce software tools that offer automated building-level assessment. With this automation comes the processing power for greater functionality, better accuracy, integration, a detailed breakdown of results and compliance with new European standards, in particular, EN 15978.

Labelling schemes for sustainable buildings such as DGNB, HQE2, BREAAM or VERDE are a driver for innovation and implementation of sustainable thinking in the European construction sector. In general, all those schemes take into account life cycle information, and in some cases, the Life Cycle Assessment (LCA) methodology is used either for assessing the whole building or for requiring environmental quantitative information on the used products in the form of EPDs.

So the industry is increasingly aware of embodied impacts (particularly carbon) and BIM has enabled powerful new tools to emerge that can integrate embodied assessment into existing workflows. The building-level assessment standard EN 15978 has been published and assessment schemes reward building-level assessment. A prerequisite to assess quantified performance is that benchmarks are developed first – so there is something to measure performance against. It is widely accepted that insufficient building-level data exist to produce robust benchmarks.

The stage is set for building level embodied impact assessment to become a mainstream activity. Expert guidance is required on how to conduct LCA studies of construction products and buildings, and how to apply the available standards and other rules. For example, the EeBGuide - Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative, (http://www.eebguide.eu/) provides information on calculation rules, metrics, provisions and instructions for LCA studies of energy-efficient buildings and building products.

Product information required for TES Life Cycle Assessment
TES manufacturers will need to deliver the information required for reliable EPD's, and case studies are needed to benchmark the building level LCA performance of refurbishments which include façade retrofits using TES. The current situation with TES sustainability is that comprehensive, specific, or typical EPD information for TES façade elements are not available, and that any material flow or embodied carbon analysis is reliant on generic information from sources with a range of values, and sometimes inconsistent data. Even with the EPD data that is available, one requires a building level life-cycle analysis to substantiate the claims of TES environmental performance, and a benchmark building level LCA with competing products, to judge the environmental assessment. With case studies at building and product level it is possible to demonstrate quantified aspects of TES environmental performance, and even so, the broader qualitative issues (social sustainability) and cost-efficiency targets are out of the scope of assessment.

Practical approach to the standards
The practical approach to applied sustainability compels one to introduce realizable measures based on previous experience of criteria for strategic targets, and allow research and development to steadily collate the evidence needed for detailed LCA, but not rely on LCA's and EPD's to be the sole measure of TES environmental performance. Even though EN15978 has objective scientific backing, it is not the only way to assess a construction product.

Complication to the standardisation of environmental assessment comes from the introduction of other European directives and standards, which lead to specific requirements for product attributes of competing construction products, and circumnavigates the core principle of CEN/TC 350, that the assessment should happen at building level, based on the integration of products and design. For example, specific demands for Green Public Procurement based on the EcoDesign Directive, Ecolabel for products, Ecolabel for buildings, Energy label for products and filtered with criteria for material safety (REACH) and material efficiency (Resource Efficiency Action Plan) means that regulatory requirements will affect the selection of materials and specification of products even before their EPD's are included in the impartial LCA calculation. Scientific and political criteria are combined in a process that loses its systematic approach.

1.3 smartTES benchmarks for ecologic, economic, social & cultural criteria

Standardized sustainability assumes a "systematic" approach to a concept of "integrated" building performance incorporating environmental, social and economic performance, as well technical and functional performance, and these are all intrinsically related to each other. The assessment assumes that the clients brief for environmental, social and economic requirements are met, as well as technical and functional requirements. This is a problematic assumption, since the clients brief is deterministic in overall sustainability. Furthermore different options (in this case options and solutions for building envelope refurbishment) are not necessarily functionally equivalent. The process of construction becomes quite systematic once it enters the contractual construction phase. However, the process of describing the brief, engaging with stakeholders, negotiation and making investment decision is not necessarily methodical, regular or orderly. It would seem logical, that a systematic, standardized and linear approach to sustainability is more appropriate to more functional works and large infrastructure projects (roads, office buildings, factories etc.) while refurbishments, domestic projects, and site specific interventions and infill should take a non-linear, inclusive, incremental and self-learning approach towards shaping targets and solutions.

Within the scope of refurbishments, there are only a limited number of alternative strategies for technical solutions with many small differences in detail. For any one project and client the designers can perform a benchmark comparison with other methods and systems in their local market. Unless the client has a specific target for life-cycle costs, quality, durability, service life, and clear priorities, there will be a tendency to make unpractical comparisons. The real point of comparison is to identify qualitative differences.

According to the concept of economic performance, the “lowest life cycle cost” building over its life cycle is the most economical one - giving good value in relation to the resources used or money spent. This implies that the building variants do not differ with respect to their functionality nor with respect to any income streams produced by the building [FprEN 15643-4 Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance] This concept of economic performance does not include developments on the real estate market, only the cost related to the building over the life cycle.

Refurbishment and modernization aims however to influence the future property value of the building by improving its desirability and quality. The assumption is that the refurbishment goes beyond immediate technical requirements of repairs, and brings some broader, enduring value to overcome obsolescence **(Section 2.3.1).**

The decision making processes of stakeholders is social by nature, since there is a connection between the motives for a solution and its' perceived desirability. These social motivations may however, override the more systematic issues of environmental efficiency, durability and cost performance. This may stem from the abstract nature of sustainability, or from personal priorities, or from overriding short term financial interests.

Due to the different nature of the dimensions of sustainability, it is important to acquaint the client, occupants and designers involved in decision making, to the economic, social and environmental trade-offs of alternative solutions. This requires a more disclosure and an inclusive knowledge-based process, with upfront investment in project management, consultation and "expertise", since fundamental decisions and commitments made in the earliest stages of a process are extremely difficult and expensive to reverse later.

It should be demonstrated that one can deliver high improvement in building energy performance applying TES retrofits - meeting national implementation of the

EPBD Energy Efficiency Directive for renovations - for a significantly reduced energy demand, in a cost-effective process, with construction product material efficiency and resource conservation that differentiates it from other comparable solutions. The balance of construction and operational impacts can be analyzed with life cycle assessment tools meeting the EN 15978:2011 (LCA) Life Cycle Assessment calculation method for environmental performance of buildings standard in order to optimize the design, and to optimize cost and environmental impacts.

In order to meet these targets, TES is a facade retrofit solution which employs material efficient prefabrication, cost-effective and fast site assembly, and a lightweight energy efficient envelope, with low embodied energy from a high degree of renewable raw materials, a high degree of refurbished and recycled building components, and a durable solution for a cost-effective use phase with minimum end-of-life impacts and long service life. To demonstrate this value proposal, all aspects of this proposition must be measured, quantified and documented.

The quantification and assessment of the life-cycle impacts for products is a complex industry led procedure, based on life cycle inventories from manufacturers. Without standardization and rules, the declarations of environmental impacts are unreliable and based on inconsistent information sources of environmental assessment data.

The core product category rules for all construction products and services have been established in European standard EN 15804 for Environmental Product Declarations (EPD). The rules for Environmental Product Declarations (EPD) specifically for wood and wood-based products EN 16485, complements EN 15804. The standardization of material specific rules allows for competing construction product sectors to present the strengths of different materials and agree on the principle trade-offs with their environmental impacts, so that a consensus is reached on common methodology for product declarations. The consensus on methodology and the use of a common database of inventories of environmental impacts is the key to the import and export of construction products between European Union member states, where the harmonization of environmental legislation reduces the outsourcing of environmental impacts to other states with looser regulation. For the Finnish construction industry, the export of products is essential, due to the limited domestic market, and common EPD regulation is vital for international trade.

1.3.1 Roadmap to Waste, EcoDesign and Green Procurement directives

TES is in a good position to benefit from implementation of the objectives of European policies and directives for resource efficient refurbishment and construction products and TES is aligned with the principles as set out in the European roadmap for resource efficiency.

According to the milestone set by the European Commission in the **Roadmap to a Resource Efficient Europe**, by 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The Life-cycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient; and policies for renovating the existing building stock will be in place so that it is cost-efficiently refurbished at a rate of 2% per year. 70% of non-hazardous construction and demolition waste will be recycled [2]

Requirements on *Green Public Procurement (GPP)* [3] within EU will favour products with reduced environmental impacts, as the common methodological approach is implemented to enable Member States and the private sector to assess, display and benchmark the environmental performance of products, services and companies based on their environmental footprint, defined as a comprehensive assessment of environmental impacts over the life-cycle. European regulation and standardization address the environmental footprint of products through setting requirements under the *Ecodesign directive* [4], to boost the material resource efficiency of products (e.g. reusability/recoverability/recyclability, recycled content, durability). [5]

"The housing and mobility sectors in Europe are typically responsible for 70-80% of all environmental impacts, and are key to addressing the challenges in energy and climate change dealt with in complementary long term strategies. Better construction and use of buildings in the EU would influence 42% of European final energy consumption, about 35% of greenhouse gas emissions [6] *and more than 50% of all extracted materials; it could also help to save up to 30% water* [7]*. Existing policies for promoting energy efficiency and renewable energy use in buildings therefore need to be further strengthened and complemented with policies for resource efficiency, which look at a wider range of environmental impacts across the life-cycle of buildings and infrastructure. Life-time costs of buildings should increasingly be considered rather than just the initial costs, including construction and demolition waste."* [8]

"Significant improvements in resource and energy use during the life-cycle – with improved sustainable materials, higher waste recycling, and improved design – will contribute to a competitive construction sector and the development of a resource efficient building stock. This requires the active engagement of the whole value chain in the construction sector. Specific policies are needed to stimulate SMEs, which make up the vast majority of construction companies – to train and invest in resource efficient building methods and practices." [9]

1.4 Core sustainability indicators

The notion of "sustainability" is abstract. It relates to the patterns of inter-relationships between concrete entities (inputs, processes, outputs, impacts etc.). The overall concept is the sum of relationships, much as a society is sum of collaborative relationships. To introduce such an abstract concept into practice requires the formulation of a consensus represented by criteria and indicators, which reveal essential features of concrete entities such as buildings that reflect our idea about sustainability. Rather than attempting to define a notion that is too abstract and context-sensitive to be a science, the scientific approach has been to define core indicators. The international standard on General sustainability principles for buildings in ISO 21929-1:2011 *Sustainability in building construction - Sustainability indicators* presents a core set of indicators for the assessment of economic, environmental and social impacts of buildings. Even so, only a third of the core indicators are quantifiable through complex calculations, standardized methodologies, and agreed parameters, and the rest of the indicators are assessed through criteria, in other words consensus about the features of buildings that display useful and beneficial properties and qualities. [10]

With ISO 21929, the quantifiable core indicators are for the emissions of greenhouse gases and ozone depletion potential, the use of non-renewable resources, water consumption, waste production, and life-cycle costs. ISO 21929 core indicators with criteria are for changes in site land-use, access to services and transport from the building location, and building accessibility, indoor conditions, adaptability, maintainability, serviceability, safety, and aesthetic quality. The fact that most criteria are not quantifiable in terms of cost-benefits, does not deduct from their importance.

Dealing with uncertainty in assessment

The results of an assessment are not always scientifically absolute, and the truth may be relativistic, but when facing the deficit of information one must extrapolate, or find generic solutions. Despite efforts to develop quantitative measures of benefits, there are situations that do not lend themselves to such an analysis. Certain projects may provide benefits such as improved quality of the working environment, preservation of cultural and historical resources, safety and security of the building occupants, and other qualitative advantages. Although they are most difficult to assess, these benefits should be documented and portrayed in a life-cycle cost analysis. Non-monetary costs or benefits can be considered within an analytical hierarchy process for decision making. Project alternatives may be evaluated using qualitative and quantitative non-monetary attributes in addition to common economic evaluation measures, in order to apply multi-attribute decision analysis methods. The external effects, externalities or spillovers of a project are an important project outputs that may be benefits or disadvantages, such as pollution or environmental loads on the neighborhood. [11]

1.5 Strategic framework for applied retrofit with TES

Sustainability is loosely defined as the balance between environmental, economic and social priorities, which in practice requires some elaboration in definition. According to the Rio Declaration on Environment and Development, at the United Nations Conference on Environment and Development, at Rio de Janeiro from 3-14 June 1992, the 5 main sustainability concepts of are integration, equity, precaution, responsibility, and participation [12]:

- *The principle of integration of environmental, social, economic and political dimensions, on all scales, from the quality and comfort of indoor environment, up to the planetary scale, and at all time, from material extraction to renovation and demolition.*
- *The principle of equity considering the inheritance, enjoyment and transmission of environmental capital from generation to generation*
- *The principle of precaution, limiting potential risks for workers, users and the environment, and considering all phases of the life of a dwelling.*
- *The principle of common responsibility for current and future needs, to protect resources, and limit impacts*
- *The principle of local participation for collective choices, multiple solutions and points of view on the scale of the collective milieu*

Key performance indicators for sustainable building renovation focus 6 priorities:

- *increase comfort of life and indoor environmental quality*
- *reduce energy consumption*
- *limit building GHG emissions (GWP)*
- *reduce drinking water consumption, and increase water resources*
- *reduce the production of waste (construction and use)*
- *reduce the consumption of resources (embodied energy and materials)*

The framework for environmental efficiency of a service can be defined using system boundaries. Inside a hypothetical site boundary, the quality of the human space and living amenities is weighed against the negative aspects of the environmental load outside the system boundary (**Figure 1-1).** This principle is used in the Japanese assessment method (CASBEE), and shows how a hierarchical qualitative approach to assessment, which differs from the analytical lists of assessment methods such as LEED and BREEAM.[13] The qualitative approach to sustainability emphasises the need to invest effort in achieving goals, to exceeding the ordinary, and to highly consider the value and perceptions of stakeholders. The benefit of this approach is to go beyond specific minimum performance requirements, and relinquish personal control but support human effort. At the centre of this philosophy, the living amenities are assessed within the continuum of the environment, rather than disconnected from the natural world.

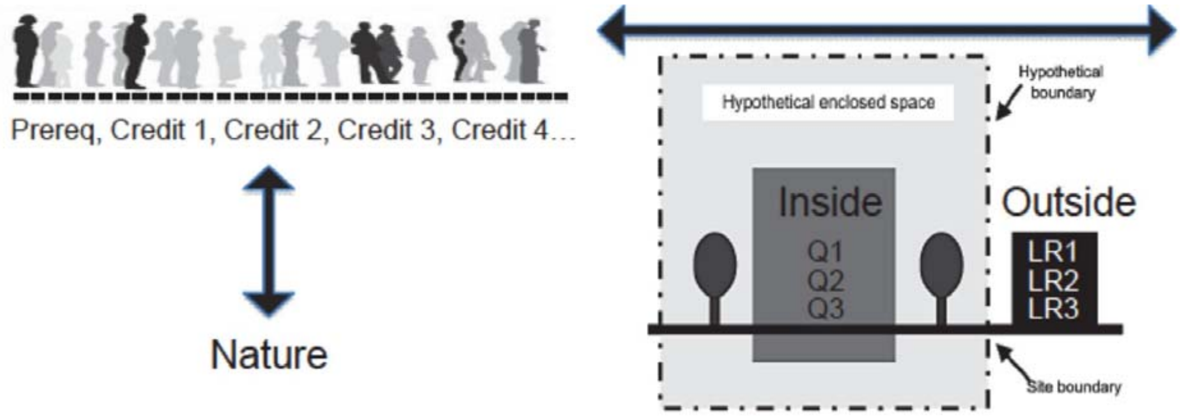

Figure 1-1 System boundaries divide site amenities from environmental load (Blaviesciunaite, Cole 2012)

1.6 Guidelines based on strategic framework

Taking a system boundary approach to TES sustainability (**Figure 1-2**), the assessment framework is organised on a on a hierarchy of scales from global to specific - from the most global and abstract level of Energy, to the most tangible and subjective level of the User, with the purpose of keeping social sustainability in focus, in order to offset the marginalisation of the end user needs, when placing effort into the physical construction process. TES evaluation according to a hierarchical strategic framework follows a clear definition of responsibilities and representatives in the refurbishment design team. Each sphere of influence should be represented, e.g. land use, energy and end-users. By the transparent collaboration of representatives, both top-down policy and bottom-up agency can be met.

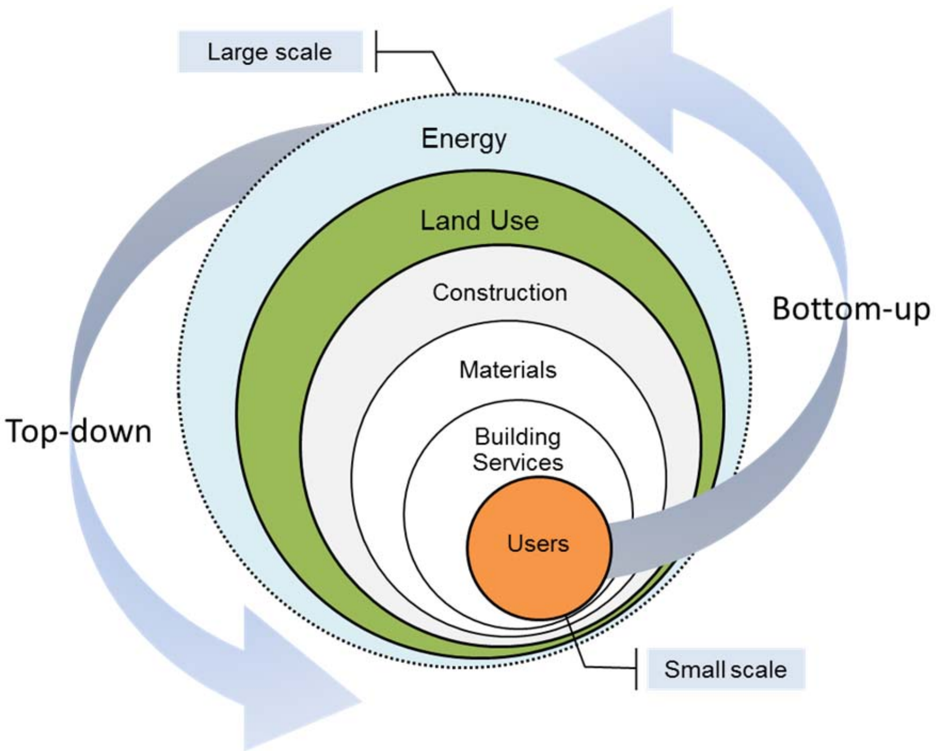

Figure 1-2 Integration of environmental, social, economic and political dimensions (le Roux)

Table 1-1 Strategic framework of Key Performance Indicators, benchmarks and measures (le Roux)

Energy

KPI
- **Global warming potential**

Benchmark
- Energy certificates
- National building regulations
- Passive house standards
- Near-zero / Zero / Plus energy buildings
- International climate mitigation strategies to reduce emissions

Measure
- Energy simulations and appropriate insulation levels
- Retrofit energy savings and energy monitoring
- Renewable energy sources
- Energy efficiency targets
- U-value and air tightness targets
- Space requirements for energy saving

Land Use

KPI
- **Change of land use**
- **Access to services**

Benchmark
- National Building and Planning regulations
- Alternative transport solutions
- "Smart" Cities – information management and infrastructure
- ERA17 – Energy-Smart Built Environment 2017

Measure
- Urban reuse, infill and extensions
- Climate adaptability: reduce surface water and flooding
- Identification of appropriate retrofit targets
- Regional value creation and local employment
- Site ecology protection and enhancement
- Design for cycling and public transport

Construction

KPI
- **Waste generation**
- **Safety**

Benchmark
- Construction site impacts and best practice
- Regulations for fire safety, structural stability
- Benchmarking for security – neighbourhood, users

Measure
- Site waste management planning
- smartTES digital work flow and process planning
- Monitoring of site energy and transport use
- Quality control
- Moisture control and rain tightness
- Consideration of residents needs during construction process

Materials

KPI
- **Resources consumption**
- **Materials and non-renewable energy**

Benchmark
- Material and product certification and EPD's
- Building assessment standards
- Product type approvals
- ISO and CEN standards
- LCA methodology

Measure
- Assessment of the environmental impact of materials
- Responsible sourcing of materials
- Water saving measures
- Facilities for reuse, recycling, and composting
- Design for durability, deconstruction, disassembly
- Analysis of material flows
- Moisture safety in material specification

Building Services

KPI
- **Indoor conditions and air quality**
- **Maintainability and serviceability**

Benchmark
- National building regulations and standards
- Best practice guidelines
- VOC requirements
- Acoustic requirements
- Indoor air quality standards

Measure
- Integration of building services
- Multifunctional smartTES
- Airtightness measures balanced with ventilation design
- Thermal comfort simulations
- Improvement in visual comfort and daylighting
- LCC of building systems
- Monitoring of building performance

Users

KPI
- **Adaptability**
- **Safety**

Benchmark
- Maintainability
- Accessibility
- Aesthetics
- Adaptability to change of use or user needs

Measure
- User design participation and anticipatory design
- Health and Wellbeing: Inclusive design
- Home user guidance
- Integration of building automation, commissioning and monitoring
- User-relevant basic services
- Cycling storage, drying spaces, home office
- Energy display, lighting design

1.6.1 Mitigating climate change through energy policy

The European Union is aiming for increased energy efficiency and reduced carbon footprint in both new buildings and buildings facing major renovations, and with the DIRECTIVE 2010/31/EU on the energy performance of buildings (EPBD) regulations set at a cost optimal level.

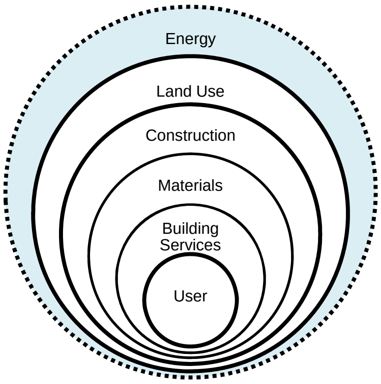

Figure 1-3 Helsinki power station museum from 1876, generating electricity on a site used for water power since the 1550's (photo: le Roux)

Figure 1-4 Energy level of influence within sustainability system boundaries (le Roux)

Political target values are typically developed in a top-down way, and these targets are translated into building specific targets. The politically motivated nearly zero energy standard or the positive energy house standard are characteristic examples. These targets represent political conventions and political feasibility. This top down approach of energy targets and policy is introduced in different countries through legal prescriptions and standards, and is often seen as a risk by the real estate industry, which in turn delays the progress and improvement in standards. Facing the slow development of standards, alternatives based on contractual obligations have been developed. Typical example is the Passivhaus Label. Among others also the housing industry has developed benchmarks for the evaluation of energy consumptions and energy-related CO2 emissions in the operating phase.[14]

EU political targets are interpreted and implemented in member states through national regulations, and building specific targets are expressed through the standardisation of an energy calculation methodology. This has created a diverse range of calculation methods with increasing complexity, but simultaneously has created a demand for expertise and consultation, which is improving the quality expected from the construction industry. As a result of the rapid evolution in energy calculations, the European Committee for Standardisation CEN has a mandate to develop overarching standards to provide consistency in integrated calculation methodology for the assessment of the energy performance of buildings (prEN 15603). The overarching standard EPBD is expected to be ready by 2015. The CEN European standards are written to be harmonised with the normative references of international ISO standards. The need for harmonised energy regulations is a balancing act of political instruments and standardisation, since flexibility is needed to provide for national options. Each member state has the right to interpret energy regulations differently, and regulations have political intent.

In Finland for example building regulations have evolved rapidly to meet EU targets, and regulations from 2012 for new buildings now emphasise the overall energy performance of a building, rather than simple numerical prescriptions for thermal insulation values for single building structures.[15] The new and first Finnish statutory regulation on the improvement of energy efficiency of buildings during renovation and alteration works of existing buildings was published in

February 2013 and is applied to all building renovation works requiring a building permit.[16]

One major energy-related impact of buildings is the CO2 emissions from the energy used for the heating of buildings. This is a variable that can - based on experience of demonstrations and research projects including TES EnergyFacade - be improved with refurbishment measures. As the passive house benchmark in the modernization of existing buildings is already proven to be feasible in northern Europe, then even near-to-zero energy applications can be possible for refurbishments. The application of TES EnergyFacade has especially focussed on improving the energy performance of residential buildings. The energy performance of an existing building can be evaluated through the analysis of yearly consumption data of heating energy and hot water which gives an indication of the Annual Heating Energy Demand per net area, kWh/(m2a). General statistics give indications on the current energy demand for general building types according to year of completion. Airtightness can be verified using blower door tests to meet the requirements for energy efficiency e.g. passive house standards. Airtightness minimizes the amount of air passing through the structure, and allows a mechanical ventilation system to recover heat before discharging air externally.

The efficiency of energy performance reached by building renovation measures can be predicted through energy simulation or calculations performed throughout the planning and design stage and verified after realization. The range of tools is constantly growing, from simple evaluation tools to complex software. TES retrofits have been evaluated with a variety of tools, some spread-sheet tools such as the German Passive House Planning Package (PHPP), and some more complex dynamic simulation software like IDA Indoor Climate and Energy (ICE) and Riuska, comfort and energy simulation used in Finland, or SCIAQ Pro Simulation of Climate and IndoorAir Quality, by Sintef in Norway.

As specifically prescribed in the EPBD the political target is to achieve cost optimal solutions to reduce CO2 emissions. By cost optimal level is meant “/…/ minimised lifecycle cost (including investment costs, maintenance and operating costs, energy costs, earnings from energy produced and disposal costs)”. [17] Experience has shown that there is no simple fix for cost optimal solutions to reduce CO2 emissions. Adding insulation to reduce heat transmission is cost effective to a point, and even so, demands a deep and broad scale intervention into existing buildings with significant changes to the building physics, which requires engineering design expertise. The energy demand from heat transmission through the building envelope can be significantly reduced after TES retrofit, but the effort in material related primary energy is many times higher than the annual transmission energy savings. As a result, the investment costs, energy targets, finance planning, and scope of design of each retrofit and refurbishment must be carefully balanced. This is an argument supporting a bottom-up approach initiated by the construction industry and real-estate sector, which is more likely to be in tune with users’ needs, and harmonised with the context of the particular retrofit or refurbishment.

1.6.2 **Land Use**

Smart land use for TES sustainability means low-carbon approach to refurbishment utilizing the embodied energy of existing structures, and reuse of infrastructure. Sustainable refurbishment means building upon the historical layers of urban culture, and the evolution of an urban ecology. The EU is densely populated and by 2020, 80 % of the EU population is likely to live in urban and peri-urban areas.[18] The environmental impacts of cities spread well beyond their physical limits, as they rely heavily on peri-urban and rural regions to meet demand for food, energy, space and resources, and to accommodate waste.

The environmental awareness behind ecological criticism of the contemporary European city is itself a crisis of modernism. The structures and urban context where TES refurbishments are applied are typically products of modernist architectural post-war developments (Finnish “lähiöt”, German reconstruction, Swedish social housing etc.).

As the built environment becomes an all-human environment, humans become cut off from the natural and the animal world around us. Humans lose the comparative frame that helps to balance their lives. Cut off from tactile participation in the real, physical world, there is an increasing tendency of humans to live abstractified lives.[19] The challenge facing the sustainability approach based on energy simulations and life cycle analysis is that these are extremely abstract concepts to most people. Energy balances and material flows quantified with CO2 equivalence are intangible concepts, and difficult to make tangible or legible, and therefore difficult to affect social behavior. It is particularly for this reason, that efforts to introduce sustainability into the built environment require a tangible dimension. Issues and measures related to land use, site ecology, sourcing of raw materials, water and waste introduce a tangible framework to embody and perceive change, and to stimulate and remind users of the more abstract processes at play.

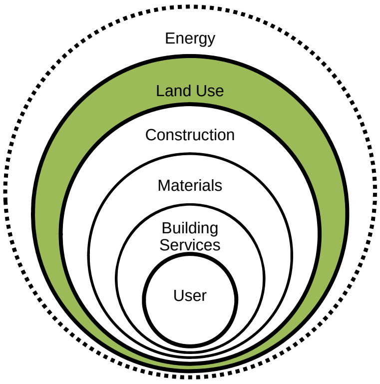

Figure 1-5 Thamesmead district in London, developed as housing in 1960’s around futuristic ideas, is in the process of urban regeneration (photo: le Roux, 2012)

Figure 1-6 Land Use level of influence within sustainability system boundaries (le Roux)

Energy represents the most abstract concept of sustainability, and its’ physical form is all but intangible. Solar radiation is the ultimate source of energy, but the most tangible level of sustainability is the physical living environment in which human life has evolved and energy becomes embodied. By the abstract nature of energy, it often goes unnoticed and unregistered in daily life, but land use as human habitat affects everyone and literally forms our “environment”.

Energy savings represent political and global targets with long payback periods, but the added value of refurbishment and the motivation for retrofits with smart systems such as smartTES must be grounded in tangible needs and benefits.

Many environmental challenges are global and can only be fully addressed through a comprehensive global approach, while other environmental challenges have a strong regional dimension. Energy policy - with the goal of reducing carbon dioxide emissions, is a global challenge. The environmental impacts on land use, on the other hand, are specifically regional. Within the EU region, the evolution of environmental policy steers national land use regulations which regulate the market for TES in the long term.

The EU Environment Action Programmes (EAPs) – of which there have now been six – have contributed to EU environment policy since the early 1970s. The sixth Environment Action Programme expired in July 2012. The European Commission has since been asked to propose a successor programme. The EU Proposal for a General Union Environment Action Programme to 2020 ("*Living well, within the limits of our planet*") contains objectives and priorities relevant to smartTES on the level of land use. The objective is to protect, conserve and enhance the EU's natural capital, and achieve a land degradation neutral world in the context of sustainable development. The degradation, fragmentation and unsustainable use of land in the EU is jeopardizing the provision of several key ecosystem services, threatening biodiversity and increasing Europe's vulnerability to climate change and natural disasters. [20]
By 2020 the EU has stated objectives to reduce EU greenhouse gas (GHG) emissions of at least 20%, halt the loss of biodiversity and the degradation of ecosystem services, achieve good status for waters, and to reduce the environmental impacts and health risks from air quality, from the use and production of chemicals, and from the generation and management of waste. Specifically the objectives include reducing the overall impact of resource use and improving the efficiency of such use, and to strive towards an absolute decoupling of economic growth and environmental degradation.

Quality of life is directly influenced by the state of the urban environment. The EU Environment Action Programme states objectives to enhance the sustainability of the Union's cities, develop an integrated approach to sustainable urban development and community led local development, and to assess the environmental performance of cities, by putting environmental sustainability at the core of their urban development strategies.

Despite the considerable importance of urban environment policy, the EU's influence in this area is relatively slight. Local decision makers determine the evolution of cities, and build upon the existing environment and infrastructure.[21]

EU environmental strategy targets:

- Densification to tackle the impacts of urban sprawl
- Improved public transport and services
- Save natural resources and energy
- Reduce emissions and pollution
- Reduce risk for social polarization
- Reduce consumption of land and soil erosion

The quality of urban planning is critical to the implementation of sustainable urban development. Changes of land use may reflect either environmental degradation, or an upgrading of built environments. Refurbishment and retrofit is added to the existing city. Urban (re)development aims to upgrade and release latent potential within neglected environments. TES, as an emerging technology, has been implemented in refurbishment pilot projects which work as catalysts to broader urban regeneration, e.g. Innova project in Peltosaari.

Urban regeneration is an opportunity to optimize existing infrastructure. The planning process connects the individual refurbishment project to existing environmental management systems for waste, energy and water, and therefore environmental services must be critically assessed within the planning of refurbishment.

Property value is said to be about “location, location and location”.[22] Thus, the potential value of redevelopment is determined by access to a range of services – environmental, transport, social, educational, commercial, and cultural. For example, assessment criteria for the proximity of key services indicate the importance of site choice, such as the access to transport nodes, and daily services.

The use of previously developed sites and the rehabilitation of contaminated land is a means to reduce land consumption and make it possible to protect land which has not been previously disturbed. Within the concept of urban ecology, TES projects must be assessed and designed taking sustainable land use into the scope of work. The refurbishment project is responsible for protecting and enhancing the existing site ecology, considering the biodiversity of the immediate surroundings, and the impact on water systems. For example, by introducing sustainable urban drainage to reduce storm water runoff and adapt to climate change and growing flood risks. The risk of flooding is a growing risk in urban areas, made worse by increased development which overloads existing storm-water drainage. Therefore retrofits offer an opportunity to improve local storm-water management, benefit from drainage design, and reduce the flooding risks associated with climate change. Housing areas which were originally peri-urban - bordering rural landscapes - are now outflanked by newer urban growth areas, and the urban stress on adjacent landscapes has increased. As a consequence, urban planning now places greater emphasis on protecting ecosystems, and increasing urban biodiversity. The quality of a refurbishment is measured against the load on the surrounding environment, and this balance indicates the level of ecological efficiency.

Responsible land use implies the sustainable management of a non-renewable resource. The priority is to use previously developed sites and/or contaminated land and avoid land which has not been previously disturbed. Examples of these land use measures can be found in guidance on sustainable refurbishment: Planning for urban infill has improved the feasibility of building reuse and extensions. Building regulations will increasingly demand improved climate adaptability, flood protection, reduced storm water runoff, rehabilitation of contaminated soil, and the planting of additional vegetation – in yards or on roofs. Developers who voluntarily implement sustainability measures can reduce environmental risks, and enhance the perceived value of their properties. Refurbishment and retrofits attract planning and funding incentives, and can better argue for financial support and investment. Refurbishment allows for the adjustment of a property’s market position, and simultaneously can benefit from improved environmental performance. Enhanced site ecology and biodiversity stewardship improves the desirability of a property by improving its intrinsic environmental quality.

Regional value creation and local employment represents the spatial dimension of social sustainability. Protectionism is contradictory to the rules of open competition, but local synergy promotes the growth of sustainable economy. For example, in the Danish “Energiby” model[23], the Frederikshavn energy city is a municipal strategy implementing a concept on low carbon city planning, in which energy refurbishments are promoted through collaboration and knowledge sharing between urban planning, home owners, and small and medium-sized enterprises.[24] The Danish energy city examples demonstrate how the implementation of energy policy needs to be rooted into the political, social and technological practicalities of a sustainable urban society. By the creation of a value chain with broad stakeholder base, there is both a supply and demand for emerging technologies. A broader approach to construction components, retrofit technologies and processes for smart refurbishment will evolve a competency network with greater leverage in the market.

Design for transport solutions which offer an alternative to the growing use of private cars is part of a holistic approach to urban environment. On a refurbishment project level, the owner can examine their own scope to improve the urban infrastructure, including improved access to public transport, provision of cycling and electrical cars infrastructure, supporting car sharing, home offices, improved pedestrian safety and reducing intrusive lighting. All these aspects are within the scope of site planning, electrical, automation and architectural design, but are easily overlooked in standard construction practice. Sustainability guidance and environmental standards provide practical advice and best practice to improve design quality with tangible benefits, and the potential to set and achieve sustainability targets must be explored before proceeding to legal and contractual negotiations for construction.

The scope of building level LCA, standardized according to EN 15804:2012, includes the impacts of construction products and construction processes, but the loads on the surrounding community are effectively out the scope of assessment for an individual refurbishment project. Location and urban context determines the market value, feasibility, scope and usability of a project, which ultimately determines the service life, payback and benefits of a refurbishment investment. The limited scope of environmental assessment and the relation between project impacts and urban context implies a need for assessment tools beyond the system boundaries of LCA and building environmental ratings. Assessment tools specifically for the evaluation and certification of sustainable urban planning are emerging as demand grows for high profile urban projects.

The framework for assessing social sustainability in building is standardized in EN 15643-3: 2012, and is exemplified by the impact of construction activities on surrounding communities. Social affordability is a measure of inclusiveness, whereby upgrading may lead to a process of gentrification and social displacement. The concentration of social and political tensions within urban systems leads to potential conflict, and therefore refurbishment is loaded with social needs. The quality of urban planning influences a broad range of social impacts, and property owners, developers and contractors should anticipate tenant and neighborhood participation. On a practical level, the anticipation and reduction of traffic disturbances, noise, water and air pollution, and neighborhood safety show the consideration of community needs which goes beyond the site boundary during refurbishments.

1.6.3 TES construction quality

The construction industry is facing a transition to an information economy, to knowledge work, and absorbing the impact of transformations in digital technology. In the face of increasing complexity, the industry must continue to create and deliver value.
The combination of global digital infrastructure and economic liberalization leads to increasing pressure for performance, and companies need to figure out how to participate in and harness knowledge flows. Existing management practices and workers' skills are becoming outdated and fail to meet the needs of the information economy. Rather than relying on efficiencies of scale, the future requires scalable learning, to help all participants to learn faster as more participants join. Lifelong learning in a rapidly evolving information society is increasingly important. Companies become decentralized organizations and move away from standardized and tightly-specified process flows.[25]

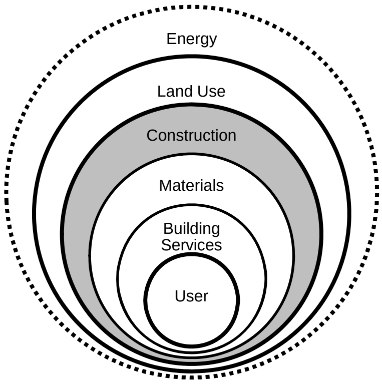

Figure 1-7 TES energy facade in Riihimäki, Finland. (photo: le Roux, 2011)

Figure 1-8 Construction quality level of influence within sustainability system boundaries (le Roux)

Within the context of the information economy, the smartTES process is an example of value creation with a knowledge-based product. When used in a construction process that does not learn from itself, this value can be lost, as the component becomes "dumbed down". The TES manufacturing and construction process cannot be a tightly specified and standardized product, as experience has already show that there are a wide range of differing TES applications, options, compositions and details. Instead, the information attached to the smartTES component needs to be retained, used, and formatted for efficient knowledge transfer.

When preparing for Environmental Product Declarations for a particular TES application, there is a need to systematically incorporate and retain a long list of product information:

- building survey data;
- structural information model;
- offsite/onsite assembly timetables;
- information about the retrofit energy performance;
- calculation of material quantities;
- product manufacturers raw material chain-of-custody and sources;
- declaration of hazardous substances;
- performance requirements for the building physics;
- site waste management records.

Sustainability verification is quantified, aggregated, documented and analyzed, and the construction industry needs to be able to swim within this data flow from the beginning of a project until the end-of-life. Having considered feasible energy efficiency targets, and harmonized the scope of work within the urban context, the successful application of smartTES comes down to the quality of the construction process. If smartTES positions itself as a system component of a high quality package of measure for holistic deep refurbishment, it should be associated with good construction quality. Otherwise the product promise is undermined by poor delivery. The contractor absorbs the legal and supply risks into pricing of construction, and when the delivery of TES becomes cost optimal, it will improve competitiveness. Quality assurance is enabled through a process of anticipatory design decisions and construction management, monitoring and reporting.

From the perspective of LCA, construction phase impacts are determined by transport associated with the construction process, the selection of products with low life cycle impacts, and their installation process.

Refurbishment process impacts are associated with the production and management of demolition construction waste. Smart waste management requires design to reduce the production of waste, and the diversion of waste from landfill. This requires a systematic approach to waste sorting and reporting, and the downstream post-processing of waste for reuse or recycling. Onsite experience has demonstrated a need to improve occupational safety and environmental management of demolition work. Again, demolition work for refurbishment is demanding, since it is partial demolition, and demands careful work. For this reason, the scope of demolition work needs to be carefully optimized, and reduced where possible. Essentially, the entire process of refurbishment is about recycling and upgrading used products (existing buildings). This makes the refurbishment construction process fundamentally different to new building, but the LCA of construction industry is still optimized for new building.

Due to the unique process of refurbishment and prefabrication, TES has a digital work flow including the need for accurate measurement of existing structures and the specification of work tolerances based on existing conditions. Increasing off-site content with greater added value is the core objective of TES, but the delivery of promised quality and project value depends on a careful logistical process. The potential time savings can be wasted if site processes and component delivery are not harmonized. The prerequisite for delivering full sustainability benefits from TES in refurbishment are a greater investment in design time, condition analysis, and prefabrication. The process benefits from the added upfront effort are realized in a better controlled site phase. Improved process documentation and recommendations based on site experience will help to make TES more attractive to contractors.

The recommendations from standards for improving social sustainability in refurbishment, for example EN 15643-3, DGNB or BREEAM are general: anticipate and respond to user priorities with participation, provide clear information and representation, arrange regular meetings with end-users, minimize disturbances and respond quickly to complaints. The culture of consumer society has become increasingly participatory, and the construction process is no longer a closed negotiation between client and contractor. End users, tenants and a wider set of stakeholders have political rights to exercise, access to social channels and many opportunities to interfere if discontented, and expectations to meet or be let down. Owners and contractors confront the reality that trust is gained slowly, but can be lost quickly. As a result, progressive construction companies specialize in user and stakeholder liaison. The recognition of end-user priorities will improve the final fitness for use, and create added value for users. Typical assessment criteria include stakeholder participation for consultation, inclusive and accessible design, building user guidance and information, and post occupancy evaluation.

Sustainability in construction phase is achieved by successfully connecting sound research to robust production processes and best practice. TES production process has been designed for faster delivery of prefabricated facades and construction quality, but the potential benefits from these design features are not realized if the TES components are added to a conventional work flow based on cheap labour and fast production turnover. Anecdotal observations on site show discrepancies in measurement tolerances (timber construction applied with concrete tolerances), and that workmanship quality does require strict supervision. Unpredicted mistakes in workmanship pose a risk to building performance, for example, with the risk of adding moisture risks, and reduce airtightness. More so, refurbishment site work exposes unpredicted issues within the original structures, and the construction company should be capable of responding appropriately to unplanned needs. Environmental risks from design and workmanship mistakes will manifest in compromised user health and safety, and unreliable construction durability. The open definition of TES detailing may result in a broad set of interpretations of material combinations and applications, where individual project designer adapt the TES model to their own interpretation of local energy and climatic needs, and within the domestic supply chain for raw materials needed for the TES components. If TES designs are subcontracted for prefabrication, the component supplier may make changes to the specified element, and the TES component as delivered on site may differ from the original research model. A systematic analysis of cases would draw some scientific evidence for future recommendations on TES building physics and standardized construction details.

Formally documented management systems support construction phase quality. Environmental Management Systems such as ISO standards specify best practice on a construction management level. On site work should be documented with pollution prevention policies and procedures to minimize air and water pollution during construction works on site. The monitoring, recording and reporting of energy, water and transport consumption data resulting from all construction processes is necessary in order to track construction site life cycle impacts. Since environmental procedures, policies and reports represent real project costs, construction companies may resist disclosures and commitments which are not included in tendering, and therefore environmental requirements need to be set by clients before procurement, or be required in building regulations. The future of tendering selection criteria for construction contracts increasingly includes concepts like eco-design in public procurement, and innovative sustainable construction systems will have a competitive edge.

Onsite targets for land use and ecology are to protect existing ecological features from substantial damage during site preparation and completion of construction works. Developers should recognize and encourage actions taken to maintain and enhance the ecological value of the site as a result of development, and minimize the long term impact of the development on the site and the surrounding area's biodiversity. Measures to protect and maintain existing ecological value require case-by-case site evaluation and design by competent ecologists and/or landscape architects, and must be included in the scope of work. It should be noted, that the scope of a typical construction project excludes site ecology and landscaping, and building regulations may not place any demands for protecting site ecology beyond the minimum requirements. A particular feature of refurbishment is that the surrounding site ecology has been undisturbed for decades since the building's original construction phase, and unless formally documented, there is always a risk that heavy handed site processes may destroy the existing site ecological value. The perceived value of the project can be protected and enhanced by the ecological value of the immediate landscape.

1.6.4 **Responsible use of constructions and materials**

"Sustainable forest products" is a wide concept. Not only does it mean that forest products are durable and recyclable, but also that wood is a renewable material. Harvested wood products store carbon, and forests have a crucial role in carbon sequestration and in replacing products such as fossil fuels, concrete and steel, which have higher carbon emissions than wood. This stresses the role of forest products in fighting climate change.

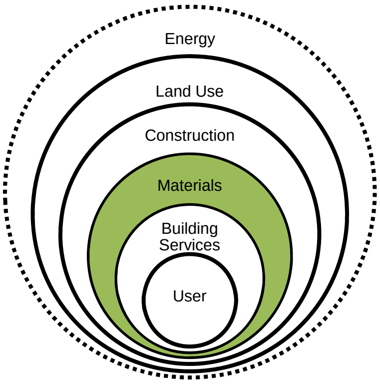

Figure 1-9 Boreal forest in Lapland, Finland. (photo: le Roux, 2012)

Figure 1-10 Material impacts level of influence within sustainability system boundaries (le Roux)

The European Forest Sector Outlook Study II (EFSOS II) report for the European forest sector presents possible futures for the European forest sector from 2010 up to 2030. EFSOS II analyses policy scenarios with different priorities: to maximize biomass carbon, enhance biodiversity, promote wood energy, and foster innovation and competitiveness. In order to maximize the forest sector's contribution to climate change mitigation, EFSOS II concludes that the best strategy is to combine forest management focused on carbon accumulation in the forest with a steady flow of wood for products and energy - maximizing biomass carbon. In the long term however, the sequestration capacity limit of the forest will be reached, and the only potential for further mitigation will be regular harvesting, to store the carbon in harvested wood products or to avoid emissions from nonrenewable materials and energy sources. It will require cross-sectoral policy making, focused policy instruments and strong political will to mobilize enough wood for energy, to implement the right balance between carbon sequestration and substitution and to conserve biodiversity without sacrificing wood supply, and thereby make the best possible contribution to the sustainable development of society as a whole. Countries should develop objective methods of assessing the present and future sustainability of forest management, preferably linked to the regional systems under development.[26]

Europeans still believe that their forests are being over-cut and shrinking in area, as well as being severely damaged by air pollution. Innovation is mainly seen as a preoccupation for the forest products industry. However, forest management also needs innovative approaches, for instance in recreation or financing biodiversity conservation or the provision of other ecosystem services. Forests can play a role in climate change mitigation by sequestering carbon (in forest biomass, soil, and/or harvested wood products), or by substituting nonrenewable materials and/or fuels. It is possible to increase the carbon stored in the forest, without affecting the total supply from the forest, but this will imply a switch from final fellings to forest thinning, which is only feasible if the industry can deal with altered quality and dimensions. Maintaining a high increment rate is important for mitigation purposes, as this is the only terrestrial process that actually removes carbon from the atmosphere. Any other actions should be targeted at keeping the carbon in the system as long as possible, or to use it as efficiently as possible to avoid emissions from fossil fuels.[27]

With the background in mind of the European forest sector, TES can support climate change mitigation through the sustainable sourcing of wood for products, and should objectively assess the sustainable development of TES for the benefit of society as a whole, and focus the use TES components on the objective to avoid emissions from nonrenewable materials and energy sources.

The central mechanism for ensuring the procurement of sustainable timber-based construction products – sometimes overlooked by end-users – is the responsible management of raw material sources and the certification of Chain-of-Custody for production materials. The countries where TES has been developed (Germany, Norway and Finland) rely on PEFC certified timber products for TES production, and this aspect of TES should be transparently presented.

Forest certification was originally introduced to prevent illegal logging, especially in tropical countries, and to develop forest management in those countries in a more sustainable direction. Most certified forests are in temperate and boreal forests. The failure of forest certification to address many of the problems in tropical forests has led the EU and the United States to introduce legislation to eliminate trade in illegally harvested wood. Forest certification and legislation to combat the illegal timber trade are important steps towards improving the image of wood as sustainably produced material. Illegal logging and non-sustainable forest management has harmed wood’s image. The role of certified forest products has increased significantly during the past two decades, and this trend is continuing. Nevertheless, public awareness of forest certification is limited, and many end-users do not understand the meaning of certified forest products. As end-users become more aware of certified forest products, the more they can be expected to demand certified or otherwise sustainably proven wood products.[28]

The two largest international forest certification programs are the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). Approximately ten percent of the world’s forests are certified and of these two thirds - about 245 million hectares - to PEFC standards and schemes. By May 2012, the global area of certified forest, endorsed by FSC and PEFC, amounted to 394 million hectares. The certified area already exceeds 50% of the regional forest area in some parts of the world. The majority of PEFC-certified forest lies in North America and Europe (mainly Finland, Norway and Sweden).[29]

By means of Chain of Custody certification, the progress of wood raw material from certified forests can be followed from forest to end product. Wood, wood fibre or non-wood forest produce contained in the product or product line can be traced back to certified forests. It is also necessary to be able to show that raw materials from non-certified forests are not from illegal sources. Recycled raw material can also be taken into account when calculating certification percentages. The PEFC logo can be attached to products whose certified raw material content is at least 70%.[30]

One third of Germany is covered by forests, more than 11.1 million hectares. With more than 320 m^3 wood stock per hectare, and therefore more than 3.4 billion m^3 in total, Germany has more growing stock than typical forest countries such as Finland. Most of the forests are located in the Southern part of Germany which also has the highest numbers of PEFC certified forests (75% - 87% of the total forest area).[31]

Forests cover 38% of the Norwegian land area. Total forest area stands at 12 million hectares, 7.4 million of which is production forest. Today’s standing forest volume is at an all-time high of 740 million m3. Practically all production forest in Norway is PEFC certified, and PEFC Chain of Custody certificates cover the majority of forest industry production and procession industry in Norway.[32]

Approximately 95% of Finnish production forests are certified under the Finnish PEFC system. In 2011 there was about 22 million hectares PEFC certified forest in Finland. Certification is of major significance to Finland as most of the products of the forestry sector are exported, and the origins of Finnish forest products are demonstrated through PEFC certification.[33]

Bearing in mind the complexities of verifying the sustainability of timber sources and that the sourcing of timber needs to be assessed in the context of forest management, it should not be accepted “de facto” that TES is a sustainable product. The sizing, quality, composition application of each façade element varies case-by-case, according to designer and manufacturer, and the transparent, quantification and reporting of specified construction materials, will make it possible to analyze and assess the impacts and benefits of the component across its life cycle.

Environmental rating systems such as BREEAM recognize and encourage the use of robust and appropriate life cycle assessment tools and consequently the specification of construction materials with a low environmental impact (including embodied carbon) over the full life cycle of the building. On the simplest level, it is possible to compare the impacts of generic material layer options for the major structural components, and on a more complex level, to audit the actual material quantifies to a high level of detail. For example, the new BREEAM International standard does not actually evaluate and rate the output results of buildings' Life Cycle Analysis, but rather compares the rigorousness of LCA tools against new European standards (compliance with EN 15978).

The chapter on **integrated modernization solutions** presents the building level of case studies of the overall material flows associated with TES retrofits, where the intention is to balance the input of new material resources and the effort required for the recycling of existing structures, to overall minimize the need for non-renewable resources, yet produce a desirable quality of life with a long service life.

Resource efficiency can be promoted via the effective and appropriate management of construction waste. However, the need to reduce the generation of product waste is not limited to individual components, and the responsibility needs to be shared by the full design team. This is the central justification for integrated design practice, where construction management, architectural, structural and building service design collaborate to improve the life cycle performance of the building, reduce the impacts of the manufacturing process of all components, improve site waste management practice, and anticipate of the future needs to adapt, maintain or deconstruct the building. The most straightforward measures are to employ a spectrum of opportunities to reuse, recycle and decompose materials throughout the building service life and occupant use; to design for durability, deconstruction and disassembly; to specify appropriate materials and construction details for moisture safety; and to specify water saving measures which reduce the demand for heating energy and the waste of clean drinking water.[34]

The chapter on **robust product engineering** presents the construction material product level, with case studies in the comparison of TES components with different material compositions. The more theoretical analysis of carbon sequestration and the reduction non-renewable primary energy are examined in the context of robust product engineering, which promotes the quality of products in order to improve service-life durability, usability, and recyclability and to reduce the risks of construction mistakes.

1.6.5 **Integration of Services**

Multifunctional service integration puts the “smart” into smartTES. Integration may take place on several levels. Physical integration of services is more complex, and may include the retrofit integration of ventilation supply air ductwork into the building envelope, or a vertical spatial extension of the building envelope to accommodate new building services such as heat recovery ventilation units. The objective of smartTES has been to promote a more holistically integrated approach to energy refurbishment, and in most cases, complex building service integration may not be feasible. These innovative cases hold potential for future renovations, when legislation demands improvements in overall energy efficiency that cannot be reached purely by retrofitting energy efficient building services.

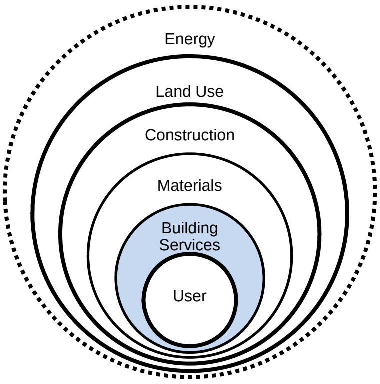

Figure 1-11 Retrofit heating in Halmstad, Sweden, and Oulu, Finland. (photos: le Roux, 2012)

Figure 1-12 Building Services level of influence within sustainability system boundaries (le Roux)

On another level of integration, the designed integration of services is more easily employed, and potentially leads to a broader approach to refurbishment and retrofits. This approach emphasises the need to perform overall calculations of building energy balance at an early stage, during design development, and for design verification and monitoring. Further design studies include the holistic evaluation of thermal comfort and heating demand, the integration of both passive and active systems, and the setting of airtightness targets and refurbishment insulation levels that integrate the design of building service systems with the refurbishment of the building envelope. The potential to retrofit a ventilation system to improve air quality and increase energy efficiency may be resolved by the physical integration of façade and ductwork, but that is not a foregone conclusion – it is just one option of a solution based on integrated service design. Other aspects of service integration which touches on TES, is design for visual comfort with balanced glare-free natural light, artificial lighting and task lighting, and the provision and option of natural ventilation through the façade or windows.

The integrated approach the design management of a construction project sets as a primary objective the selection of long-term cost-effective investments based on the comparison of alternative proposals. The environmental best practice example from BREEAM describes the use of Life Cycle Cost (LCC) analysis (in accordance with ISO 15686-5:2008) to be carried out based on the proposals developed during concept design or design development stages. With LCC analysis critical elements should be analyzed at a strategic and system level, to compare alternative options. Realistic options are used for comparison (meeting the performance criteria for the building) and the lowest discounted LCC over the period should be preferred, assuming that their selection results in sustainability goals: lower building energy consumption over the operational life span of the building, and/or reduction in maintenance requirement/frequency, and/or extended service lives resulting in fewer replacement intervals, and/or dismantling and recycling or reuse of building components.

For best practice in design and construction, evaluation by LCC analysis should be updated during design development/technical design stage, and results of the

analysis implemented in the specification, design and final construction of the assessed building, and a maintenance strategy should be developed, informed by the LCC analysis. Maintenance strategies specify how to support or access systems to facilitate safe, efficient and cost-effective operation and maintenance; facilitate the removal and replacement of major plant and equipment; and provide a management plan for the landscaping).[35]
From the experience of environmental assessors in European commercial projects, LCC is rarely undertaken in practice only motivated by the BREEAM rating systems, as the additional work for analysis is a specialist field. It is reasonable to assume that large commercial projects with complex and expensive systems could absorb the cost of LCC analysis, but refurbishment projects aim to limit the scope of work to the essential, and the recommendation for future TES research and development would be for a generic LCC analysis with recommendations and options to lower building energy consumption, reduce maintenance requirements, extend service lives, and anticipate the dismantling, recycling or reuse of TES components.

On the most practical level, the integration of services represents the integration of the refurbishment process, where the refurbishment of the building envelope is delivered concurrently with the provision of other end-user services, such as the refurbishment of bathrooms and kitchens, the improvement of waste services, the provision of communal services, and the designed upgrade of internet access, cycling facilities, public transport access, or stormwater drainage and gardening facilities. The building refurbishment collects an array of services, direct and indirect, and the investment in the construction process is an opportunity to integrate the unified effort to create added value for the end users.

Finally, the integration of building services means a coherent and collaborative approach the design, installation, adjustment and monitoring of building performance, which goes over the contractual boundaries of separate tasks. Facility management, technical service and building automation design, spatial design, user needs and owner investments are coordinated, to educate and assist the end-users with energy displays, and through design, enable energy efficient and “sustainable living”.

1.6.6 Recognizing social needs in refurbishment and retrofits

The refurbishment construction process is subject to the complex demands of site conditions. Similarly, the anticipation of end-user needs is complicated by inhabitants, tenants, owners, shareholders and stakeholders prior to the start of refurbishment work, and often living during the refurbishment process on site.

The concept of sustainability is as broad as the definition of society, and guidance is about encouraging efforts, promoting innovative solutions, and enabling the will to change. *The desire to change the world is patent and simple, but it inscribes a story that is infinitely complex — as complex as the interplay of the everyday gestures that describe the way the world already works*.[36]

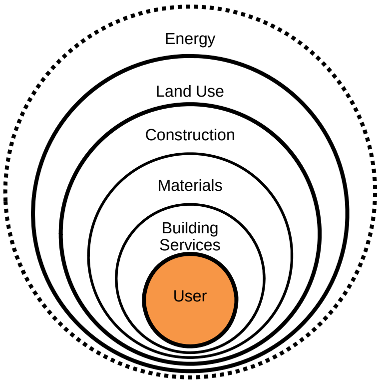

Figure 1-13 Housing undergoing energy retrofit in Voiron, France. (photo: le Roux, 2012)

Figure 1-14 End user level of influence within sustainability system boundaries (le Roux)

Investment in refurbishment is motivated through a social process, which is by definition a “bottom-up” process. This contradicts the top-down policy approach to energy efficiency, which through technical complexity, abstraction and global scope, is alienating to end-users motivated by cost-saving trade-offs, needs for urgent repairs, individual priorities, and the desire to improve their quality of life.

Quality assurance negotiates through the trade-offs between expectations and feasibility. It takes a process of mediation and collaboration to design refurbishment *fit for purpose*. The needs of occupants should be recognized as a key issue when assessing solutions for fitness of purpose. There are generally accepted policy targets to improve residents’ quality of life with modernization and urban upgrade projects, and goals to create added value for end-users of existing buildings. However, tenants often have few opportunities to have their personal needs recognized, unless there is dedicated social participation.[37] Surveys of residents’ opinions are one option, but this feedback should be developed and analyzed, because sustainable development will only work together with the understanding and commitment of individual dwellers.[38]

The need for residents’ approval demands consultation, but the need to limit costs does lead to compromises in the scope of work and final priorities for work are set by building owners. The challenge is to set stakeholder requirements, perform quality assurance for end-users, and monitor needs during the development phase, so that requirements may be verified during the final delivery and handover.

A technical construction led approach to energy efficiency tends to focus on systems and structures which are eventually concealed (insulation), encased (mechanical ventilation), or appear unchanged (heating and electrical). In science and engineering, a black box is a device, system or object which can be viewed in terms of its input, output and transfer characteristics without any knowledge of its internal workings. Its implementation is "opaque" (black).[39] The same principle is applied to much of the infrastructure of daily life (waste management, fresh water, sewerage, etc.) The retrofitted system and structure holds little potential to explicitly affect user behavior. A concerted effort is required to inform and educate end-users about the operating and monitoring of technical systems. In most cases, user interference is discouraged, and the technical complexity increases. This places more demands on facility management, and the system becomes designed to be fool-proof may be susceptible to grand failure if maintenance is neglected. The retrofitted building offers little potential to affect end-user behavior.

Simple interventions and measures which assist occupants are for example the provision of dedicated storage facilities for operational-related household waste streams and so help to avoid waste being sent to landfill or incineration. Urban agriculture, landscaping for sustainable urban drainage, water recycling or water saving systems promote a more tangible approach to sustainable living which engenders change. A “biophilia” approach to design incorporates living systems which create a sense of connection to biological systems. Human preferences toward things in nature, while refined through experience and culture, are hypothetically the product of biological evolution.[40]

Occupant engagement is achieved through participation in choices for final finishes, the provision of visible real-time energy and water use data and clear reporting of costs and amounts for parameters which occupants control, with intelligent building automation systems, and end-users empowerment through interactive feedback in the operation and maintenance of buildings.

There is no simple recipe for user driven refurbishment, since it is socially and culturally diverse, based on empirical experience and subject to human failure. Anticipatory project management, active client relations, collaborative design workshops, residents social media, clear communication strategy, nominated responsibilities and contact persons, are approaches to inclusive design which complement the competent delivery of holistic refurbishments. Socially accessible design indicates the shift towards educated consumer demand-led market. Over the decades of building sustainability assessment the innovations such as site waste management, LCA calculations, and energy simulations have led to the acceptance of better construction practice, and the standardisation of social aspects in construction works should drive similar acceptance.

The problems of residents living on site during the refurbishment process can be tackled by good site management. The TES process reduces user disturbances with off-site prefabrication and discrete site assembly. This suggests that a similar approach should be taken for other site processes; otherwise the full benefits of prefabrication will be lost. Site waste management, dust and pollution control, visitors’ site accessibility and occupants’ safety and workers occupational safety, site lighting, and site information management will cohere and promote trust between contractors and users. A comprehensive “user-friendly” approach to minimal disturbance in retrofits and refurbishment support the value proposition of the smartTES process. Without which, TES EnergyFacade, as a simple construction component, will compete against cheap labour, minimum quality, and generic solutions, with disturbances that users will put up with for lowest up-front costs. A value proposition based on long-term payoff in energy efficiency is inadequate to convince decision makers who as themselves have individual needs.

The subject of Social Sustainability is standardised in the European context, which assists the systematic evaluation. EN 15643-3:2012, *Social Aspects in the Life cycle stages of construction works present aspects for consideration in social performance assessment*. User issues related to the use and operations of buildings are accessibility, adaptability, health and comfort, maintenance, safety and security. The use of the building should not create “loadings on the neighbourhood", and the impact on social infrastructure such as public transport, and the social affordability and cost efficiency (as a cost to society) should be considered. Neighbourhood and stakeholder involvement is to be considered during planning, and during the construction process contractors should consider issues of traffic disturbance and noise, social standards of construction process (safety and neighbourhood protection). The end of the use of the building should not generate hazardous materials and pollution, and be designed for easy disassembly, reuse or recyclability.[41]

1.7 TES retrofit quality assurance (performance)

The broad goals of improving the sustainability of TES require the understanding of the building and building modernization as a holistic system of energy policy and carbon emission reductions, climate change mitigation, urban ecology and upgrading, best practice in construction technologies, smart building envelopes, integrated building services, innovative architecture, anticipatory social aspects and participatory end user engagement. European and international standards for assessment present the consensus of the basis of broad sustainability principles. Voluntary environmental rating systems are well established and available for assessing individual projects based on detailed design documentation which is the responsibility of project teams to provide. As such, the principles, key indicators, and benchmarks present a spectrum of options for evaluating performance which do not aggregate well – qualitative targets, quantitative simulations and calculations, and checklists of performance criteria are weighted differently according to national priorities, and present an indicator of improvement over current minimum requirements, which themselves constantly improve. The imperative to reduce carbon emissions and improve energy efficiency is driving a top-down regulation of construction practice, which will continue to motivate the adaption of TES energy facades. On the other hand, the other aspects of sustainability measures are predominantly voluntary, and require a design team led approach to creating a holistic value proposition for smartTES.

Improved technical quality is a development priority for TES manufacturers. Current manufacturing selects materials of the basis of cost-efficient supplies, and manufacturers established supply chains. Within each manufacturing facility, there is a localized material efficiency and manufacturing tooling, and without an established demand for TES components, there is a financial risk involved in changing the manufacturer's material process. As a result there is a variety of material compositions and measurements associated with the core TES element – sawn or engineered structural timber (CLT/LVL/OSB) and a variety of board materials (plywood, fibreboard, gypsum fibre), insulation materials (cellulose, mineral wood, glass wool) and additional membranes, vapour barriers, rain shields, let alone the open selection of cladding materials. The most realistic approach is to perform LCA analysis on a range of model compositions, so that they establish the benchmarks for TES material environmental impacts, and compare on a case-by-case how much the final composition deviates from the benchmark. With this aim, the chapter on ***robust product engineering*** presents LCA Toolbox case studies. Manufacturers and structural designers carry individual responsibilities for project specifications, but TES as a standardized product system will require stringent benchmark studies.

Safe and healthy indoor environment requirements are the result of successfully integrated design development and construction work quality. Issues of design for moisture safety, and the specification, design and installation of airtight assemblies and windows should provide a robust platform for appropriate building service integration. It is critical, that engineering design, production modelling and as-built details are cross referenced for approval, since minor changes to design may be critical. Despite the proposition that TES is timber-based, the component relies on an array of associated materials: sealants, adhesives, artificial membranes, metal connectors, insulation materials, fire-safety materials, and so on; of every increasing complexity, so that the list of potentially hazardous materials that are associated with the assembly of a TES component is subject to environmental scrutiny, such as REACH European Community Regulation on chemicals and their safe use, and compliance with national regulations and owners requirements for material safety and ecolabelling.

Figure 1-15 Monitoring building physics and heating energy after TES retrofit for E2ReBuild demonstration project in Oulu, Finland. (photos: Karhumaa (Fidelix), and le Roux, 2012)

It is imperative that TES is associated with on-going efforts to monitor and verify actual performance in energy and building physics. Potential issues will only appear after several years of seasonal variations. By the collection of actual performance data, it will be possible to compare simulated and achieved quantitative data. Standardised methodology will facilitate fair comparison of data across national localisation with clearly defined default parameters, and therefore the CEN 371 Energy Performance of Building project group is developing the EPBD Overarching Standard, currently at draft version prEN15603. The target is standardised energy assessment calculations, and standards for measured energy ratings and comparison with calculations. The assessment of building physics is more localised according to climatic adaption, but SINTEF have demonstrated and presented the comparison of simulated and tested performance results, which develop accuracy and test sensitivity in performance simulation methodology.

The development of applied sustainability concepts requires the testing of innovative retrofit solutions. Successful sustainability concept implies that a solution is appropriate to a unique set of conditions. The general political targets of carbon sequestration, energy efficiency, feasible real estate modernization and urban infill may be met, and adapted to site specific ecological conditions, but so too should be met project management quality targets, TES manufacturing product development, and specific, community and end-user social aspects.

1.7.1 **Monitoring performance**

A common saying in management is *"you cannot manage what you do not measure".* It is unsure who said that, although the quote is usually attributed to Peter Drucker (1909 - 2005). More certain is Lord Kelvin's saying in 1883 that *"when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind...".*

It is possible to evaluate retrofit on the basis of measured operational impacts on the environment. Metrics for measurement data are needed in order to monitor and improve performance and resource efficiency and to predict future behavior. This is especially true for comparing inputs (primary energy, resource use), process quality (comfort and indoor air) and outputs (emissions and waste). For this reason, environmental assessment stresses documentation and collection of evidence. Yet, at the same time, for other issues, the opposite is true that *"the most important things cannot be measured",* as stated by W. Edwards Deming. As Lord Kelvin said, scientific proof is more satisfactory, but more often, one needs to approximate and predict performance based on simulation. For this reason, the standardization of energy performance methodology requires measured energy ratings to be compared to calculations, and thereby improve calculation methods, and identify reasons for poor actual performance. Measured data is also critical for contractual issues, where service life performance is promised, and targets are set.

The declared service life of a building after refurbishment may be assumed to be 30 to 50 years depending on the extent of refurbishment. However the service life varies for different parts of the building, and there is a need to make it possible to individually upgrade separate building components and systems in an orderly sequence without major disturbances. Owners and project managers must anticipate the need to monitor actual building performance for verification, and set infrastructure in place (smart building, automation, logging etc.) to collect feedback data from the end-use, operations and management of buildings. A short term refurbishment solution is not worth the effort and investment, since a temporary solution will lead to continuing repairs, disturbances and replacements. Each component and system has its own inherent cycle of maintenance, repair and replacement, and effective monitoring anticipates the need for adjustments to settings. Monitoring tasks are needed to verify sustainability over a longer period. Relying on technology to solve problems has a spin off, in that technical systems require more maintenance, feedback and monitoring. Newly retrofitted systems - added to existing buildings - particularly require testing with maximum and minimum loads, and for seasonal variations over several years. The combination of new systems in old structures will cause changes - for better or worse - to building physics and performance. With good diagnostics, the system may be optimized and possibly added to with modular system architecture, or phased in over its own service life.

Due to the need for scientific data and evidence, environmental assessment tends to be based on detailed standards and specifications. For example, assessment core issues can be summarized on a single page, but the BREEAM assessment manual is an unwieldy 500 pages, excluding the national regulations and European standards which define the details of the criteria. The communication of assessment results is different for different audiences - designers require specific criteria, while owners and investors require only key performance indicators and aggregated weighted ratings that summarize and communicate performance and reflect the overall quality and value of a property. Common metrics for building performance[42], in the form of key performance indicators (**Figure 1-16**), can be understood and applied by property and financial markets, and assist to attach economic value to sustainable building development.

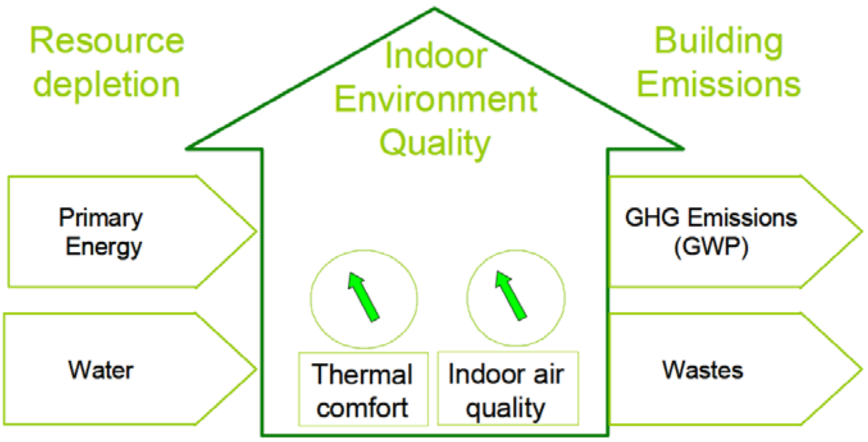

Figure 1-16 Key Performance Indicators (KPI) provide a common metric which can be understood and applied by property and financial markets (source: SBA 2009 Common Metrics)

1.8 Sustainability verification in refurbishment

Practical guidance and indicators to identify potential for sustainability are required to meet both existing and future regulations, and an increasing demand for cost efficient improvements to environmental quality. Refurbishment and retrofit distinguishes itself from new building, in that existing end-users, site conditions and building conditions are the pint of departure, not the end result. Therefore a traditional linear construction process is not feasible, due to the wide set of limiting parameters at project outset. Due to the broad scope and scale of sustainability, the design process is non-sequential, but uses an iterative process to increases the level of detail and aims for synergy in various dimensions of sustainability.

Sustainability evaluation begins with the collection of relevant background information to perform a pre-assessment consultation, in order to scope the work for sustainability potential. Site and building condition survey, initial stakeholder participation and feasibility study, and initial discussion with urban planning authorities, establishes the context for the development. The site and building conditions fundamentally dictate the final outcome. User feedback evaluates the fitness of purpose for the project. It is essential to evaluate the potential scope of work as early as possible, and come to terms with the site limitations and opportunities. Compared to speculative development, it is worth investing upfront in design work, since the options for the scope of work are greater than with new building. Broad stakeholder participation helps to identify small improvements and benefit from user observations and experiences. Small site-specific improvements and innovations are easy to overlook with a generic scope of work. The purpose of an environmental pre-assessment is to distinguish easy targets and unrealistic targets, and set a range of opportunities which may be prioritised and considered for design development.

A more complete early stage assessment may be performed when assembling the design team. Compared to typical design for renovations, a more ambitious target for sustainability requires additions to the scope of work in the description of services. Energy analysis based on thermography survey and airtightness tests, and proposals for both building services and envelope will need to be repeated for early stage, design development, detail design and final design review. More detailed analysis of options for material specifications and prefabrication, and increasingly, a need for some level of LCA recommendations. If deeper refurbishment and prefabrication is feasible, then there will be a greater need for expertise in site management and sufficient ordering time. This allows greater time for detailed design, in order to gain the maximum benefit and added value from prefabrication. A rushed design process will reduce to opportunities for a fast site process, and the associated sustainability benefits and opportunities may be lost.

Integrated design development should incorporate architectural, structural, building service engineering and automation, site planning, landscape design, and sustainable assessment in project management. Landscape planning and automation are easily left out until the last moment, and both carry benefits for sustainability. Landscape design enhances the connection of the project to the surrounding landscape and reduces ecological risks, and integrated building automation hold great potential in the future use, monitoring and maintenance of the building. The early establishment of a full design team will have greater capacity to create a holistic sustainability framework for a project than with traditional sequential planning. The conventional approach to building refurbishment is construction driven with fixed targets and optimised process, but a design driven approach holds potential for a continuous development process and dynamic modelling approach more typical of information modelling and simulations which typify the needs of sustainability.

The verification of sustainability targets demands a commitment to the monitoring, documentation, reporting and evaluation of design, production, delivery, commissioning and end use of the renovation, refurbishment and retrofit of buildings. This additional documentation and work is becoming a job in itself, and is a feasible service to offer, since the end result is a database of life-cycle data and valuable experience for an increasing demand for sustainable refurbishment, irrespective of the construction system selected. As with energy consultation, the evaluation of life-cycle and environmental aspects is becoming integrated into the standard services of the construction industry. Construction tendering is conservative and based on established practice, while sustainability is loosely defined and promotes innovation and future projections. There is a clear need for contractual form to embrace both the robustness of construction process, and the life-cycle opportunities of sustainability.

1.8.1 **Environmental Assessment of TES system properties**

The characteristic property and intrinsic strength of TES is the improved energy efficiency and thermal comfort of the building envelope achieved with low structural material impacts (LCA), and the use of an innovative technology based on prefabricated.

Potentially, the refurbishment process may demand construction waste management which may, or may not be, in place or insufficiently monitored or reported. The large volumes of insulation materials employed have different environmental impacts depending on their specification.

The threats to the TES process are externalities: unexpected site risks and impacts or problems uncovered during partial demolitions, pollution caused by dust and water pollution caused during construction. Potential problems may arise from measurement mistakes, and the interpretation of fire and material safety regulations could lead to additional costs. The supply chain of raw materials or components may lead to delays or irresponsible sourcing or undocumented chain-of-custody or the use of components with unknown properties.

The greatest range of economic, environmental and social benefits associated with the implementation of TES in construction processes are potential opportunities. This is where effort, competency and foresight are required in order to incorporate sustainability measures into the scope and design of a project. For example, the opportunity could be to balance the investment in both built envelope and building technical services to achieve good energy efficiency rating (balancing energy demand and system efficiency), or to include the participation of a wider group of stakeholders, as well as to facilitate future property management. By developing multidisciplinary teams around TES, the component becomes just one aspect of a refurbishment service product, which delivers intangible quality and reliability, as well as construction robustness. TES becomes smart.

In a SWOT analysis (**Table 1-2**) of a refurbishment process with TES against environmental assessment criteria, the criteria reveal the strengths of the TES energy facade in improving the energy efficacy of building with poor energy performance, but that there is a risk associated with generating construction waste and that material impacts can have both impacts and benefits according to design. The opportunity for TES is to be associated with overall sustainability in procurement and project management quality, and to be used in projects which reach for ambitious energy targets, and improve the indoor quality with the new envelope. There are external threats in the application of TES of producing hazardous waste, having to verify fire safety, or making poor choices which affect site impacts, or choosing to refurbish a building that has a poor location. BREEAM certification criteria are used in the example SWOT analysis of refurbishment with TES retrofit (**Table 1-2**), but similar indicators can be used from ISO sustainability core indicators, DGNB certification criteria, or any one of several available sets of assessment criteria, as demonstrated in a synopsis of ISO sustainability core indicators with DGNB and BREEAM criteria for new building (**Table 1-3**).

Table 1-2 SWOT analysis of TES related refurbishment measures with BREEAM criteria

Strengths (internal)	**Weaknesses (internal)**
Improves energy efficiency of envelope	Needs construction waste management
Low material environmental impact	Varying insulation material impacts
Improves thermal comfort	
Innovative technology and process	
Opportunities (external)	**Threats (external)**
Integrate sustainable procurement	Unverified sourcing of materials
Sustainable project management	Risks of construction site impacts
Responsible construction practices	Demands and risks of fire safety
Good post-refurbishment energy rating	Risk of volatile organic compounds
Improve visual comfort and daylight	Risk of poor site selection

Table 1-3 Synopsis of ISO sustainability core indicators with DGNB and BREEAM criteria for new building. The potential benefits of smartTES are highlighted (le Roux, Ott)

		ISO 21929-1: 2011 Core Sustainability Indicators	DGNB International 2012 NBV criteria (New Office)		BREEAM International 2013 * additional issues for refurbishment
BUILDING LIFE CYCLE IMPACTS	1	Global warming potential Ozone depletion potential	ENV 1.1	LCA – emission related environmental impact	**Mat 01** Life cycle impacts of materials (LCA) (**Mat 02** Hard landscaping included in LCA) **Pol 01** Impact of refrigerants **Pol 02** NOx emissions
	2	Amount of non-renewable resources consumption by type (natural raw materials and non-renewable energy)	ENV 2.1	LCA – Primary Energy LCA ENERGY	**Ene 01 Energy efficiency** Operational energy demand Primary energy consumption Total CO2 emissions * Refurbishment energy efficiency improvement **Ene 02** Energy monitoring **Ene 03** External lighting **Ene 04** Low and zero carbon technologies **Ene 05** Energy efficient cold storage **Ene 06** Energy efficient transport systems **Ene 08** Energy efficient equipment **Ene 09** Drying space
			ENV 1.3	Responsible Procurement	**Mat 03** Responsible sourcing of materials **Mat 04** Insulation
	3	Amount of fresh water consumption	ENV 2.2	Potable Water Demand and Waste Water Volume WATER	**Wat 01** Water consumption **Wat 02** Water monitoring **Wat 03** Leak detection and prevention **Wat 04** Water efficient equipment **Hea 04** Water quality
	4	Amount of waste generation by type (hazardous and non-hazardous)	TEC 1.6 ENV 1.2	Ease of dismantling and recycling Local Environmental Impact	**Wst 01** Construction waste management **Wst 02** Recycled aggregates **Wst 03** Operational waste **Wst 04** Speculative indoor finishes
LAND USE	5	Site: Change of land use	ENV 2.3	Land Use	**LE 01** Site selection **LE 02** Protection of site ecological value
			SITE 1.1	Local Environment SITE	**LE 03** Mitigating ecological impact **LE 04** Enhancing site ecology **LE 05** Long term impact on biodiversity **Hea 07** Natural Hazards (e.g. flooding) **Pol 03** Surface water run-off **Pol 04** Reduction of light pollution
			SOC 1.6	Quality of Outdoor Spaces	**Hea 08** Private space
			PRO 2.1	Environmental impact of construction site / construction process	**Man 03** Construction site impacts **LE 06** Building footprint
			SITE 1.2	Public Image and Social Conditions	
ACCESS	6	Location: Access to services by type: public and private transport, green and open areas, basic user services	SITE 1.3	Transport Access TRANSPORT	**Tra 01** Public transport accessibility **Tra 04** Maximum car parking capacity **Tra 05** Travel plan **Tra 06** Home office
			SOC 2.3	Cyclist Facilities	**Tra 03** Alternative modes of transport
			SITE 1.4	Access to Amenities	**Tra 02** Proximity to amenities
	7	Accessibility of building site Accessibility of building	SOC 2.1 SOC 2.2	Public Access Inclusive Access	**Hea 06** Safe access * Refurbishment Inclusive Design
INDOORS	8	Indoor conditions,	SOC 1.1	Thermal comfort	**Hea 03** Thermal comfort
		air quality,	SOC 1.5	User influence on building operation	
		visual conditions,	SOC 1.2	Indoor Air Quality	**Hea 02** Indoor air quality
		and acoustic conditions	PRO 2.3	Systematic Commissioning	* Refurbishment Ventilation and VOCs
			SOC 1.3	Acoustic Comfort	**Hea 05** Acoustic performance
			SOC 1.4	Visual Comfort	**Hea 01** Visual comfort (*daylighting)
			TEC 1.2	Sound insulation	* Refurbishment Sound Insulation
			TEC 1.7	Sound Emissions	**Pol 05** Noise attenuation
			TEC 1.3	Building Envelope Quality	(**Ene 01** Energy efficiency)
	9	Adaptability to change of use	ECO 2.1	Flexibility and conversion capability	
		or climate change	TEC 1.4	Adaptability of Technical Systems	
USE	10	Life cycle costs	ECO 1.1	LCC – Building related Life Cycle Cost	**Man 05** LCC and service life planning
			ECO 2.2	Commercial Viability	
	11	Maintainability	TEC 1.5	Cleaning and Maintenance	**Mat 05** Designing for robustness
	12	Safety in use, Fire safety,	SOC 1.7	Safety and Security	*Refurbishment Security
		Structural stability	TEC 1.1	Fire safety	*Refurbishment Fire safety
	13	Serviceability	PRO 1.1	Comprehensive project definition	**Man 04** Stakeholder participation
			SOC 3.3	Layout Quality	
	14	Aesthetic quality	SOC 3.1	Design and Urban Quality	
			SOC 3.2	Integrated Public Art	
PROCESS			PRO 1.2	Integrated planning	**Man 01** Sustainable procurement
			PRO 1.3	Comprehensive building design	*Refurbishment Project Management
			PRO 1.4	Sustainability aspects in tender phase	
			PRO 1.5	Documentation for Facility Management	
			PRO 2.2	Construction quality assurance	**Man 02** Responsible construction practice
					Innovation and exemplary performance

1.8.2 DGNB Assessment tools comparison

The sustainability principles established in international standards such as ISO or CEN are top-down assessment frameworks consisting of core indicators. Their implementation and assessment within the construction industry is made through the available assessment tools. It is not practical to assess and compare individual projects on basic principles alone; there is a need for specific criteria which refer to detailed calculation methodology and definitions. The certification of buildings provides a framework to quantify and demonstrate the positive aspects of a construction project that aims to differentiate itself through sustainability. The German DGNB certification system aims to be an advanced system for sustainability assessment, with the emphasis on LCA, practical implementation – especially for high quality commercial and public buildings – and optimized for German and European norms and building regulations.

Certification is a documentation of investors' commitment to sustainability and high quality, and enhances the perceived value of real estate, to improve the chances for the sale and rent of property as a performance-enhancing work environment with high user satisfaction. Certificate evaluates buildings' overall performance and not just individual measures. The DGNB certificate aims to exceed the ecologic aspects of “green building” by also including criteria evaluating economic performance, as well as socio-cultural and functional aspects of buildings.[43]

An important aspect of certificate systems is their ability to be frequently updated and adapted in line with new technical, social and international developments. For this reason the dominating certification systems such as LEED, BREEAM and DGNB continue to lead in real estate consulting. Commercial certification is a benchmark of construction industry best practice, and a credible framework for the market evaluation of smartTES sustainability and for declaration guidelines to the assessment of sustainability of TES components and method.

DGNB and BNB Assessment and certification system

An overview made of the leading sustainability assessment system in Germany and the BREEAM system demonstrates different approaches taken to evaluate construction projects. The German sustainable building council system (DGNB) is still relatively young and has been developed since 2007. DGNB calls itself a second-generation system, because it takes into account all aspects of sustainability in construction, including specific economic, social, technical and process-oriented criteria in addition to the assessment of environmental characteristics, which is a focus of earlier systems. The private DGNB system made its market entrance in 2009 and since then has offered a growing range of schemes for various building types. The public BNB system was later introduced, based on the same fundamental scheme of sustainability aspects.

The BNB system has been developed by the German Ministry of Transport, Building and Urban Development (BmVBS) for buildings of the German Federal Government on the basis of the first DGNB system. The BNB system aims to create two new schemes for existing buildings. These pre-release versions have only a limited amount of criteria compared to the new building scheme. The first scheme under development is the BNB office and administrative building - use and operation (BNB Büro und Verwaltungsgebäude – Nutzen und Betreiben = BNB BV-NB), which assesses the operation of existing Federal Government buildings.[44] Buildings are documented according to their current operational quality and evaluated without any retrofit or refurbishment measures. The schemes contain criteria to assess ecological sustainability (e.g. greenhouse emissions from heat and power consumption), social sustainability (e.g. actual user satisfaction), and process sustainability (e.g. operational control and management). No criteria for technical sustainability are included, because these can only be influenced by construction activity. The second BNB scheme for existing buildings aims at the office and administrative building stock / complete measures for rehabilitation of existing buildings (Büro und Verwaltungsgebäude – Bestand / Komplettmaßnahme

= BNB BV-BK).[45] Criteria come from all aspects of sustainability; in addition to several environmental criteria, numerous criteria are available from the aspect of the rehabilitation process. They deal with the complexity and optimization of planning, building analysis and demolition measures. Criteria related to user oriented issues are not listed in the social aspect, and there are no conversion process issues in the criteria for process quality.

Contemporary rating systems like DGNB and BNB are performance oriented and require quantitative evidence to meet assessment criteria; e.g. the evidence for environmental quality demands Life Cycle Assessments and energy calculations. The social and process aspects go beyond other evaluation systems. Both aspects are very important from the perspective of building rehabilitation, since new measures during ongoing building operations may be unavoidable. This results in the need for specific assessment frameworks for construction processes just as for new building. The unique conditions of the conversion process in building rehabilitation require special attention in the context of sustainability. The existing buildings must be examined in close connection to the local environment where interventions will have impacts. The observation of life cycle is a fundamental principle of a sustainability assessment.

German Sustainable Building Council requirements for smartTES

The DGNB rating system can be applied to guidelines for smartTES on the basis of the scheme for new construction office building. The system for existing buildings and rehabilitation is still under development and not yet applicable. Nevertheless the scheme for office buildings contains principles and criteria valid for deriving other schemes. The requirements and criteria are not all relevant for smartTES, because TES is only one component that is manufactured for a specific method and applied as an energy facade to existing buildings. SmartTES becomes one part of a building and contributes to its overall quality.

The TES method considers the entire building in an integrated, sustainable process in order to enhance it. Due to the multifunctional potential of smartTES elements, it is possible that they can serve more than a single function of wall insulation, but also be the basis of different functions. This includes of course the facade cladding, but it also incorporates components such as windows or elements of the building services into the SmartTES element. Off-site prefabrication transfers large parts of the manufacturing work away from the site to suitable production facilities. The goal of prefabrication is a high level of integration of different components up to the surface-finished assembling of the components off-site.

The goal of the smartTES sustainability guidelines is to outline requirements for the information that is needed to assess the application of the TES system. This allows comparisons with alternative rehabilitation and refurbishment solutions, and gives guidance to decision makers, to evaluate the TES elements within the scope of a sustainability analysis. For the declaration guideline, the DGNB catalogue of criteria has been checked in terms of the SmartTES system, in order to select eligible criteria and describe their relevance to smartTES.

From an overview in the table of relevant DGNB criteria, it can be stated that a significant number of criteria from all sections of the DGNB assessment system have direct relevance to smartTES. This demonstrates the applicability of this assessment system in assessing smartTES. The elimination of assessment criteria in preliminary investigations do not mean that these must not be considered for modernization projects when working with TES elements. The selection of the criteria depends on whether the TES elements are affected directly by the individual criteria requirements.

Table 1-4 Overview of DGNB criteria relevant for SmartTES declaration guideline (Ott)

DGNB Criteria - Scheme NBV (New Office Administration)				
	Criterion	**Objective**	**TES relevance**	**Notes**
DGNB Criteria for Environmental Quality				
ENV1.1	**LCA – emission related environmental impact**	Reduction of environmental impact over the whole life cycle, for protection of the global environment.	**YES**	The global environmental impact of construction products manufacturing is also related to smartTES, and an important part of an LCA.
ENV1.2	**Risks for local environment**	Protection of people, flora and fauna from dangerous substances, which can reach groundwater, surface water, soil and air.	**YES**	The materials used in facade components must be examined with regard to their risk potential. Urban and neighbourhood social structures must be accounted for.
ENV2.1	**LCA – Primary Energy**	Protect global climate and resources by reducing life cycle primary energy consumption and increasing the renewable energy share.	**YES**	The primary energy content of building materials and components, including SmartTES elements, is an important part of the LCA consideration.
DGNB Criteria for Economic Quality				
ECO1.1	**LCC – Building related Life Cycle Cost**	Economic use of financial resources by minimizing total life-cycle costs (costs of planning and production, occupancy, and disposal)	**partial**	Life Cycle Costs related to choice of cladding and degree of facade multifunctionality. Not evaluated in SmartTES.
ECO2.1	**Flexibility and conversion capability**	The building concept should have internal flexibility and enable an easy conversion to reduce the risk of standing empty.	**YES**	The technical equipment of the building is part of this consideration. This criterion should be closely considered, due to the possible integration of building service systems in multifunctional elements.
ECO2.2	**Value retention, Sustainability for third-party use**	A building should have the potential to be accepted by the market over the medium and long term.	**partial**	Location, image, parking accessibility and current market property plays a role in this criterion. The facade affects the perception of a building and influences its value.
DGNB Criteria for Sociocultural and Functional Quality				
SOC1.1	**Thermal comfort**	Rooms should be designed for pleasant room temperature and humidity and be free from draught.	**YES**	The improvement of air tightness and heat transfer coefficients by the TES elements influences the thermal comfort of spaces.
SOC1.2	**Indoor Air Quality**	Ensuring an indoor air quality that does not affect the well-being and the health of the user.	**YES**	External TES elements over existing walls will not affect indoor air. Non-structural facades (infill or curtain wall) may be replaced by TES elements, so interior material choices have a role.
SOC1.5	**User influence on building operation**	Allow users to control aspects of indoor comfort according to individual needs.	**partial**	Possible influence of multifunctionality and its control (e.g. shading). TES elements as such are irrelevant here.
SOC1.7	**Safety and Security**	Increase the user safety by protection against intrusion and reduction in potential harm or loss in such events.	**YES**	The reduction in possible harm considers the risk of fire from pyrolysis among other things. The criterion assesses indoor materials.

DGNB Criteria for Technical Quality				
TEC1.1	**Fire safety**	Fire protection through constructional and technical measures.	**YES**	Fire safety is relevant to TES. Regulatory demands made on TES core as a non-load bearing part of the outer wall, and on facade surfaces.
TEC1.2	**Sound insulation**	Noise protection in non-residential and work areas, and from external and building service noise sources.	**YES**	TES elements influence sound insulation from outside noise.
TEC1.3	**Hygrothermal quality of the building envelope**	Reduction of heating needs, ensuring thermal comfort and protection from moisture damage.	**YES**	TES elements, whose main intention is thermal optimization, are important for this criterion.
TEC1.4	**Adaptability of building services systems**	Future enhancements and modifications to equipment should be allowed, because they are frequently subject to change.	**YES**	Amongst other systems, this applies to vertical shafts for building services, which can be integrated in multifunctional smartTES elements.
TEC1.6	**Ease of dismantling and recycling**	Recycling of materials and reduction of waste in a material cycle by enabling as complete a material recovery as possible.	**YES**	The expenses for disassembly and separation of components in the field of "not constructive elements" must be evaluated for smartTES elements.
DGNB Criteria for Process Quality				
PRO1.1	**Comprehensive project definition**	Optimized end results with early planning and agreed objectives.	**YES**	These criteria are general approaches in the planning phase, which is of great importance for the realization of retrofit projects using the SmartTES method.
PRO1.2	**Integrated planning**	Improve planning and final results with early coordination.		
PRO1.3	**Comprehensive building design**	Interdisciplinary development of concepts and studies of options for optimal overall solutions.		
PRO1.4	**Sustainability aspects in tender phase**	Inclusion of sustainability criteria in tendering documents and in selection of companies to improve environmental and social quality of building.	**YES**	This criterion is related to SmartTES, but sustainability aspects must be considered in tendering and procurement procedures for all variations of facade retrofit.
PRO2.1	**Environmental impact of construction site / construction process**	Minimize the burden from waste, noise, dirt and dust at construction sites on the environment and local residents.	**YES**	SmartTES can offer advantages by reducing construction site work and methodically limit site noise, dust and construction site waste.
PRO2.2	**Construction quality assurance / quality control measures**	Perform quality assurance and control at the site and document materials and safety data sheets.	**YES**	A high degree of prefabrication of TES elements establishes preconditions for quality assurance, documentation of materials and measured test results.

1.8.3 BREEAM Assessment tools comparison

The BREEAM assessment standard is also worth examining as an example of an assessment method applicable in European countries where TES has been employed. BREEAM serves the purpose of a commercial tool for voluntary assessments, and as an established benchmark of construction best practice. BREEAM is applicable to smartTES, since it has introduced new tools that are tailor made for the assessment of domestic refurbishments, based on the UK national code for sustainable homes. As with other commercial certification standards, the regular updating of assessment criteria demonstrate the development of internationally standardized energy assessment methodology. The newest assessment standard was released in June 2013.

Commercial assessment standards
The BREEAM environmental assessment method consists of a set of commercial certification standards that clients can apply to the design and construction and operation of buildings. The goal for voluntarily certification is to mitigate the life cycle impacts of buildings on the environment, to enable buildings to be recognised according to their environmental benefits, to provide a credible, environmental label for buildings, and to stimulate demand for sustainable buildings. Most BREEAM assessment issues are tradable, meaning that a client/design team can select which criteria to target in order to build their assessment score and achieve the desired environmental rating. Several issues have minimum standards meaning that to achieve a particular certification rating certain criteria must be achieved. [46]

TES core issues
BREEAM addresses core issues relevant for the assessment of projects which use TES. Sustainable construction site management is a holistic approach to the delivery of environmental performance, recognizing opportunities in stakeholder participation, and ecological site protection. TES is used in order to improve energy efficiency, but with lower material life cycle impacts than other measures for energy refurbishments. The users of TES could improve their environmental achievements by placing additional emphasis on life cycle costing and service-life-planning, providing evidence of responsible sourcing of main materials and insulation materials. The majority of environmental assessment issues are not directly connected to TES components, but the inclusion of TES within a holistic sustainable package will reinforce the reputation and credibility of TES, and support the perception of innovative refurbishment project management.

TES environmental safety
Issues of fire safety, robustness, and VOCs (volatile organic compounds) may be a potential concern for TES safety, but an examination of BREEAM reveals no criteria which pose a problem for TES. VOCs and other hazardous construction materials are a growing concern in building regulations, and it would be prudent for TES manufacturers to supply evidence of VOC test results and declarations for any potentially hazards or emissions from materials used in TES elements.

TES energy efficiency
Opportunities to improve energy efficiency and environmental quality in a refurbishment project should be pursued in all building systems and components; otherwise the investment costs and the construction process impacts, time and disturbances may not have delivered its full potential. System losses and energy uses from other components offset the gains made with TES facade energy and material efficiency, e.g. heating transfer losses, household appliances, comfort heating, ventilation systems, miscellaneous electric load and standby electricity consumption.

Triple metric energy efficiency calculation
A new calculation methodology for determining the number of credits achieved in the energy efficiency assessment issue has been introduced in to the BREEAM International New Construction 2013 version (energy criteria Ene 01). This methodology is a departure from previous versions of BREEAM, which awarded credits based solely on a single carbon emissions metric. This change was made to promote designs that minimize energy demand and consumption in buildings, and then to reduce the carbon emissions resulting from that energy use.

The energy efficiency calculation methodology considers three metrics of modeled building performance, as follows:

1) **Energy demand:** This measures how well the building reduces heating and cooling energy demand, it is influenced by factors including building fabric heat loss and air permeability.
2) **Primary energy consumption:** This measures how efficiently a building meets its energy demand. It is influenced by factors including the type of building services systems specified and the efficiency of the energy generation and distribution.
3) **CO2 emissions:** This measures the amount of carbon dioxide emissions the building emits meeting its operational energy demands. It is influenced by factors including building fabric performance, systems and distribution efficiency and fuel source. The specification of low or zero carbon forms of energy generation (on site, near site or accredited external renewables) are accounted for in this parameter and they may also have a positive influence on primary energy consumption where they are displacing nationally supplied electricity or gas.

This triple metric approach ensures that standard practice against the energy efficiency or consumption scale cannot be completely offset by best practice against the carbon performance scale through the specification of low or zero carbon, on or off-site energy solutions. Therefore, BREEAM seeks to encourage and reward a holistic approach to reducing energy and CO2 emissions, through a balance of good building design and systems specification.

It should be noted for countries which have been involved in the smartTES project that BREEAM follows the Köppen Climate Classification System, and that Finland and Norway are classified as Snow-temperate climates, while Germany is classified as Warm-temperate. This distinction affects the requirements for assessment criteria, and highlights the need to systematically localize criteria.

1.8.4 BREEAM New Construction compared to Refurbishment

The 2012 pilot version of the BREEAM domestic refurbishment assessment standard has been compared in detail with the UK Code for Sustainable Homes assessment standard for new built homes. The comparison was made to verify the scope and suitability of their assessment method for refurbishment.[47] The BREEAM refurbishment assessment has also been cross referenced with a new international assessment scheme for new building. As yet, there is no international or European assessment method for refurbishment. Refurbishment assessment standards derive from standardised collections of assessment issues. This British domestic refurbishment standard demonstrates a reasonable scope of assessment, and their new international scheme demonstrates international assessment methodology. Criteria for energy efficiency assessment and material efficiency in particular should be examined in detail for TES benchmarking.

BREEAM New Construction is an assessment standard for new residential, offices, industrial, and retail constructions in design and post-construction phases. Other building types can be scoped for assessment, but this standard is not intended to assess infrastructure projects, community level master planning projects, *or the refurbishment, fit-out, operation and deconstruction of existing building*.

Rating systems aim to support innovation in the construction industry by making additional credits available to recognize sustainability related benefits or performance levels that are currently not recognized by standard assessment issues.

The assessment weighting for the energy category is significantly higher (43%) in the BREEAM Domestic Refurbishment 2012 standard, than in the BREEAM New Construction standard (19%).This corresponds to the tightening legal requirements for new construction, while energy improvements with refurbishment are predominantly voluntary. In refurbishment projects, the BREEAM method excludes the categories for transport and land-use, so this places more emphasis on other categories. Note, that energy efficiency, improved indoor environmental comfort, and water savings are the main aims for domestic refurbishments, together carrying over 70% of the weight of the environmental assessment rating. Energy, water, lighting and ventilation target values are specific numerical targets. Accessibility, site drainage, natural light, acoustics, responsible procurement, environmental management and ecological protection, and other various measures are not quantifiable target values, but together have clear qualitative benefits.

BREEAM Domestic Refurbishment 2012 is a pilot scheme that looks at assessment issues and measures relevant to refurbishment projects. The site specific conditions are excluded from assessment categories for ecology and transport, since the designers and owner cannot change the building location, and work within the existing context. Some individual issues affecting site ecology and transport are included within other categories of energy, pollution and site management. In a report on the comparison between the assessment of new homes and domestic refurbishments, BREEAM describe how they have scoped their refurbishment assessment standard, as opposed to the Eco-homes assessment scheme for new domestic buildings.[48]

BREEAM Domestic Refurbishment aims to encourage improvements to building envelope thermal performance and resilience to climate change in existing housing stock, as a cost-effective response to the major weaknesses and risks in existing buildings. Management, Health & Wellbeing and Energy categories have higher weightings for refurbishment projects than with new domestic assessments.

The Primary Energy Demand criteria have more credits in BREEAM Domestic Refurbishment than the equivalent Eco-homes comparative issue, because BREEAM follows the consensus that gives precedence to improving the building fabric efficiency of the dwelling. The “fabric first” emphasis on lower U-values and higher thermal efficiency is consistent with TES Energy Facades. The improvement in energy efficiency carries weight for refurbishment in order to make it a primary concern for clients and designers. More focus should be on the improvement to energy performance than on the overall efficiency rating.

The BREEAM Refurbishment 2012 assessment standard offers a simplified and prescriptive approach to reducing material impacts, and recognises that the main objective of retrofit is to improve the thermal performance of the building envelope. BREEAM have developed a material impact calculator for retrofit facades which compares the relative improvement in building envelope U-values (as a measure of investment in improved thermal performance) against generic ratings for the embodied environmental impacts of the new materials added to the envelope. The best overall thermal improvement with the least material impact (simplified environmental performance rating) will score highest.

By comparison, the newest BREEAM 2013 International standard recognises the new European standards for LCA calculation methodology, but only includes major refurbishment in the scope of environmental assessment, since only a major refurbishment is comparable to new building.

Innovation credits have been incorporated into domestic refurbishment assessment to promote exemplary performance for chosen environmental issues. Innovation may be credited for excellent energy performance, data collection of energy consumptions, very low water use, refurbishment site waste management planning and resource efficiency, on-site management of surface water, exemplary construction practices, ecological protection, thermography surveys and airtightness testing, and inclusive design for lifetime homes.

Conclusions have been drawn from reviewing the assessment results from several BREEAM domestic refurbishment pilot projects, to see where environmental performance tends to be better or worse, and, find which aspects of refurbishment are overlooked in assessment.[49] Criteria for materials achieve lowest scores in domestic refurbishment pilot assessments.

Materials with higher embodied impacts may be needed to deliver energy efficiency improvements or to gain operational savings. For this reason, the priority should be on improving the building fabric, and benefit from refurbishment of building envelope, which will have a low material impact but improved energy efficiency. The total embodied impacts of materials in refurbishment are much lower than in new building, due to a reduced need for new materials. There is a need to differentiate between the benefits of existing materials while looking at the impact of the new materials. Attention is paid to assessing the embodied impacts and responsible sourcing of thermal insulation materials, since they are of great importance in retrofit building envelopes. It is important to note that the re-use of existing elements is credited in BREEAM for refurbishment, unlike in assessment methods for new buildings. By retaining existing materials and improving the energy efficiency, credits are awarded for both low material impact, and improved energy efficiency. In other approaches to the assessment of materials, the existing materials are excluded from life-cycle assessment, but this would appear to be an unfair approach towards the overall material balance, since retained existing materials are combined with new materials for improved thermal benefits and service life, displaced from waste streams, and offset new construction impacts.

Refurbishment has limited influence on site related issues such as surface water, transport and ecology. Good site selection is critical for sustainability, but for renovation, retrofit and refurbishment the site is already given. Owners should consider these issues in the investment decision, since there is little that can be done if the site has major problems.

Criteria for Energy, Waste, Water and Management categories achieve highest scores in BREEAM domestic refurbishment pilot assessments. These four categories represent the main priorities in BREEAM for refurbishment, and have cost-effective potential for achieving environmental ratings. Existing house stock has varying initial energy performance, so performance should be assessed relative to the pre-refurbishment starting point. However, both relative and absolute energy performance should be assessed. Buildings with poor initial energy performance improve rapidly with even minimal improvements, while buildings with higher initial performance struggle to make decent energy savings, because they already have pre-existing measures to improve energy performance, or the existing requirement is less of a dominant factor.

The comparison of BREEAM refurbishments revealed some limitations in assessment and verification. The comparison case studies represent leading edge pilot projects, and do not fully represent the full range of refurbishments. It will still take some time before environmental best practice is “diffused” in mainstream construction. Refurbishment included many measures specific to individual projects, but assessment methodology sets criteria which can be used to compare a large sample of projects. For this reason, attention is paid to the scoping of assessment methods according to building type, size, use and location. Environmental assessment should recognize small changes that reduce environmental risks, but small changes are not comparable. The incorporation and testing of innovative retrofitting technology is not given sufficient recognition in assessments. Again, this is due to the particularity of innovation, which cannot be predicted by a generalised assessment method.

Environmental rating systems for buildings have focused of new buildings, since the initial impact of an entire new construction is greater than refurbishment. However new building activity only represents a small fraction of the future overall building stock, and the need for refurbishment is growing. Assessment for refurbishments is important, to encourage and improve the environmental approach to these projects, which hold great potential for future energy savings.

The success of the refurbishment is a measure of the improvement in overall performance relative to original conditions, as well as the absolute performance in the future. Both relative and absolute energy efficiency have real benefits and financial incentives. The reduced impacts of material flows do not carry direct financial incentives; therefore the reduction on material flows needs to be incorporated into the package of robust product innovation and life-cycle quality. LCA data and responsible material sourcing demands effort with information management, but emphasises and communicates the intrinsic value of TES: structures sourced from sustainable forestry, combined with safe materials, detailed for quick and simple assembly, appropriate to climate, durable and robust, part of a well-managed site process, improving long term energy performance, supporting indoor environmental quality, recognizing end-user needs, and anticipating future maintenance, repairs and disassembly for reuse and recycling.

Table 1-5 Comparison of assessment criteria for new construction and refurbishment and Strengths, Weaknesses, Opportunities and Threats for the application of TES (le Roux)

BREEAM International New Construction 2013: Assessment categories (weighting %), and issues	**BREEAM Domestic Refurbishment** 2012: Assessment categories (weighting %), and issues	**TES** SWOT
Management (12%)	**Management (12%)**	
Sustainable procurement	**Project Management**	**O**
Responsible construction practices	**Responsible Construction Practices**	**O**
Construction site impacts	**Construction Site Impacts**	**O**
Stakeholder participation	**Home Users guide**	**O**
Life cycle cost and service life planning		**O**
	Security	O
Health and wellbeing (15%)	**Health and Wellbeing (17%)**	
Visual comfort	Daylighting	O
Indoor air quality	Ventilation	O
Thermal comfort		O
Water quality		
Acoustic performance	Sound Insulation	
	Fire safety	**T**
Hazards	**Volatile organic compounds (VOCs)**	**T**
Private space		
Safe access	Inclusive Design	O
Energy (19%)	**Energy (43%)**	
Energy efficiency	**Improvement in Energy Efficiency Rating**	**S**
	Energy Efficiency Rating post refurbishment	**S**
	Primary Energy Demand	**S**
Energy monitoring	Display Energy Devices	O
Energy efficient external lighting	Lighting	O
Low and zero carbon technologies	Renewable Technologies	O
Energy efficient cold storage	Energy Labelled White Goods	n/a
Energy efficient transportation systems		n/a
Energy efficient laboratory systems (TBC)		n/a
Energy efficient equipment (process)		n/a
Drying space	Drying Space	O
Transport (8%)	*Transport category excluded for refurbishments*	
Public transport accessibility		O
Proximity to amenities		O
Alternative modes of transport	Cycle Storage (under Energy category)	O
Maximum car parking capacity		O
Travel plan		O
Home office	Home Office (under Energy category)	O

Water (6%)	**Water (11%)**	
Water consumption	Internal Water Consumption	O
	External Water Consumption	O
Water monitoring	Water Meters	O
Water leak detection and prevention		O
Water efficient equipment		O
Materials (12.5%)	**Materials (8%)**	
Life cycle impacts	**Environmental Impact of Materials**	**S**
Responsible sourcing of materials	**Responsible Sourcing**	**O**
Insulation	**Insulation**	**O**
Designing for robustness		
Waste (7.5%)	**Waste (3%)**	
Construction waste management	**Refurbishment Site Waste Management**	**O**
Recycled aggregate		O
Operational waste	Household Waste	O
Speculative floor and ceiling finishes		O
Land use and ecology (10%)	*Land use category excluded for refurbishments*	
Site selection	Flooding (under Pollution category)	**T**
Ecological value of site and protection of ecological features	Protection and enhancement of ecological features (under Management category)	**O**
Enhancing site ecology		
Long term impact on biodiversity		
Building footprint		**O**
Pollution (10%)	**Pollution (6%)**	
Impact of refrigerants		n/a
NOx emissions	Nitrogen Oxide Emissions	O
Surface water run off	Surface Water Runoff	O
Reduction of night time light pollution		O
Noise attenuation		O
Innovation (10%)	**Innovation (10%)**	
New technology, process and practices	**Exemplary performance**	**O**

1.9 Investing in sustainable refurbishments

The decision to undertake a deep intervention into an existing building is not made lightly. Long payback periods for deep interventions may go beyond the life times of individual private owners, and repairs postponed until they cannot be avoided. It is human nature to avoid confronting inconvenient facts. Ambitious energy targets are driven in the long term by political policy, since voluntary measures tend to be short term cost optimizations. The top-down policies enforcing targets for energy retrofits run the risk of being a case of financing the needs of future generations, but compromising the ability of current generations to meet their own needs.

The reasons for investing in an extensive modernization are often driven by social issues, to improve living conditions, and by the perception that a building is outdated. The motivation to raise the capital value of a property may contradict the interests of residents who benefit from cheap accommodation and for economic reasons cannot afford to move or invest in higher quality accommodation. Rather than being only focused on energy modernization, the decision makers need to consider a broad range of issues which may be decisive in motivating and justifying the investment decision. These motivations vary nationally, according to location, typology, condition, ownership and cultural values.

Thomas Lützkendorf points out the need for a simple and reliable set of sustainability indicators which communicate the sustainability credentials of a property, and allows these credentials to be translated into economic property value: *The issue of integrating sustainability aspects into the property valuation and appraisal process has also been the topic of various international initiatives and larger-scale research projects./.../ However, the main focus of most of these initiatives and research projects is the consideration of the energy performance of buildings within the valuation and appraisal process. Other sustainability aspects are also addressed but not yet to the same extent. This is due to the fact that energy performance is one of the most tangible sustainability issues and is often used as a proxy for wider issues. /…/ The increased interest across different groups of market participants in issues of sustainability creates not only a new demand for reliable information, but also the need for feeding this information into traditional and new instruments and methods of the property industry*.[50]

The report of the *TrainRebuild* project [51] revealed that the key driver for demand of energy efficiency in buildings is closely linked to improved property value. Energy efficiency retrofit represents a relatively long term, high volume and low value investment for financiers which carries a high administrative burden (large number of small loans) as well as high risk as there are no recognized ‘experts’ on which to rely for risk assessment. Mechanisms to aggregate energy efficiency projects (such as large scale retrofit programmes) could make investments in this field more attractive with potential aggregator roles for municipalities. Consistent and long term regulatory framework and funding programmes would further help to realize the cost-effective energy saving potential of the building sector. This is the only way for the industry to realize the market development potential, for financiers to support the process and for property owners to get involved.

Property owners should be encouraged to develop community projects and form partnerships with local authorities to facilitate large scale retrofits and benefit from preferential interest rates and economies of scale. Property owners require independent trusted guidance from energy advisors specialized in building.

Retrofits are not only justified by increased energy efficiency to reduce exposure to increasing energy costs, but also to secure and increase the capital value of the property, and increase rental value. By improving the comfort and health standards for residents, the demand and attractiveness of the property is increased, and tenancy or ownership is more secure. Therefore the project feasibility and scope needs to assessed top-down (energy efficiency) and bottom-up (residents' needs).

1.10 Conclusions

TES Energy Façade (Timber based Element System) is a facade retrofit solution which employs material efficient prefabrication, cost-effective and fast site assembly, and a lightweight energy efficient envelope, with low embodied energy from a high degree of renewable raw materials, a high degree of refurbished and recycled building components, and a durable solution for a cost-effective use phase with minimum end-of-life impacts and long service life. The characteristic property and intrinsic strength of TES is the improved energy efficiency and thermal comfort of the building envelope achieved with low structural material impacts (LCA), and the use of an innovative technology based on prefabricated.

The use of TES for refurbishment has been shown to support the preconditions to achieve good environmental ratings, improved energy performance, and reduces life cycle impacts, with robust low-tech measures, observing detailed prescriptive criteria, and also analysed with advanced LCA methodology. It is feasible and recommended to include a broad range of sustainability targets into a refurbishment project, and enhance the overall performance with project management, and with a bottom-up approach to end-user and stakeholder needs, and the application of specific tangible measures. The broader holistic view enables upfront integrated design to deliver a fit-for-use building, with durable environmental, economical, technical, social, functional and process quality.

Taking a system boundary approach to TES sustainability, an assessment framework is organised on a on a hierarchy of scales from global to specific - from the most global and abstract level of energy, to the most tangible and subjective level of the end-user, with the purpose of keeping social sustainability in focus, in order to offset the marginalisation of the end user needs, when placing effort into the physical construction process. TES evaluation according to a hierarchical strategic framework follows a clear definition of responsibilities and representatives in the refurbishment design team. Each sphere of influence should be represented, e.g. land use, energy and end-users. By the transparent collaboration of representatives, both top-down policy and bottom-up agency can be met.

The scope of building level LCA, standardized according to EN 15804:2012, includes the impacts of construction products and construction processes, but the loads on the surrounding community are effectively out the scope of assessment for an individual refurbishment project. Location and urban context determines the market value, feasibility, scope and usability of a project, which ultimately determines the service life, payback and benefits of a refurbishment investment. The limited scope of environmental assessment and the relation between project impacts and urban context implies a need for assessment tools beyond the system boundaries of LCA and building environmental ratings.

TES manufacturers will need to deliver the information required for reliable EPD's, and case studies are needed to benchmark the building level LCA performance of refurbishments which include façade retrofits using TES. The current situation with TES sustainability is that comprehensive, specific, or typical EPD information for TES façade elements are not available, and that any material flow or embodied carbon analysis is reliant on generic information from sources with a range of values, and sometimes inconsistent data. Even with the EPD data that is available, one requires a building level life-cycle analysis to substantiate the claims of TES environmental performance, and a benchmark building level LCA with competing products, to judge the environmental assessment. With case studies at building and product level it is possible to demonstrate quantified aspects of TES environmental performance, and even so, the broader qualitative issues (social sustainability) and cost-efficiency targets are out of the scope of assessment.

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2. Integrated modernization solutions

Stephan Ott
TUM Technische Universität München

Simon le Roux
Aalto University School of Arts, Design and Architecture

2 Integrated modernization solutions

2.1 Sustainable building processes

2.1.1 Introduction

Sustainability considered in the refurbishment of existing buildings from the post-war period, from the 1950s up to the 1980s, is talking about nearly half of the building stock throughout Europe. These buildings have insufficient technical and functional standards and very high emissions during operation. On the other hand they are often attractive, inner-city located with spacious green areas in the international style of the erection time. It requires action of the housing industry due to the problem of obsolescence of the building stock.[1] They are the aim of huge efforts to reduce the huge operational emissions. Through the social structures that exist locally and are interwoven with the surrounding, adequate procedures are required to contribute to sustainable development.

Reduction goals of primary energy demand in 2020 and 2050 will bring very long-term effect for greenhouse gas emissions and thus achieve the climate protection goals.[2] It must therefore be discussed in more detail the embodied emissions and the resulting environmental impacts, especially that the occurrence of those emissions is happening right now.[3] There is a temporal divergence between these two issues that should be considered in decision making on the retrofit method and the material and its embodied emissions. Darby uses economic methods and models for the discounting of emissions, and he applies it to the new building. We contend that it is similar mechanisms in the renovation. However, where there is still an emission bonus due to the recovering of existing substance. That was installed a long time ago and its embodied carbon is already partially or completely absorbed by the environment. The reduction of greenhouse gas emissions is approached by different measures. Either change the power supply (energy turnaround, ger: Energiewende) and the related reduction of CO2 emissions, or reduce the PE demand in buildings:

- Reduction of transmission and convection heat loss from buildings
- Improving the efficiency of building services and new technology
- Use of passive environmental energy (solar buildings)
- Use of active environmental energy (local energy production)

All measures aim at the operation of buildings and the reduction of operational emissions. No measure considers necessary inputs in energy and material for retrofitted buildings. The embodied energy for the material production and the embodied emissions related to this input is happening right now and is much higher than an annual reduction of operational emissions.

In new construction the additional embodied energy to achieve a net zero energy building is low relative to the total effort for the basic construction [4]. In retrofit the embodied emissions are directly related to building performance and the resulting operational emissions. This issue will be evaluated in this work package. The main outcome will be essential metrics for the reduction of the energy demand of as well as the material effort, with all inputs and outputs and their embodied emissions.

2.1.2 Holistic integrated modernization with TES

An isolated technical consideration of the task of refurbishing the building envelope for energy efficiency is not possible. The complexity and dependencies in refurbishment projects with the goal of sustainable value generation requires a holistic approach. There is a variety of impacts on the local and the global environment, on users as well as on economic. Overcome building obsolescence and provision of durable solutions is the field where smartTES offers alternatives with specific qualities who manage impacts and complexity. [5]

The refurbishment and retrofit of existing buildings for expected economic value generation includes not only the facades but also windows, roofs, building services systems, and very often interiors like bathroom and kitchen. The task is growing in complexity due to rising efficiency demand by regulation in the field of energy as well as material resources[6] [7]. This brings uncertainties not only on the social-technical level but also on the environmental and economic level. Designers and planners have to deal with the uncertainties of the future development of resource availability and energy grids while clients very often cannot oversee the complex situation and the consequences of decisions.

In order to allow innovative solutions and deal with complexity, a whole life cycle scenario is necessary. Buildings generate values over a long time and buildings are long lasting goods, therefore the consequences of high investments have to be overseen for their whole life cycle. Another obliging conceptual approach is a necessity of flexibility in the design solution and the design process itself that allows right from the beginning during the programming phase great openness for alternatives. The opportunity of flexibility will decline during design works and transforms into a narrow gap at the end of the process. With both concepts of whole life cycle approach and flexibility in design process a higher resilience towards uncertainties is possible. Risks inherit in each refurbishment project are going to be manageable.

SmartTES as a new refurbishment method might be risk factor at first glance, because it incorporates an unknown process and new materials. The process is innovative in a way that it opens valuable alternatives for retaining existing buildings on the other hand side it brings uncertainties into the decision making. Tackling major uncertainties of the process is task of the research projects TES EnergyFacade and smartTES.[8] Solutions and experiences how to properly manage risks are shown.

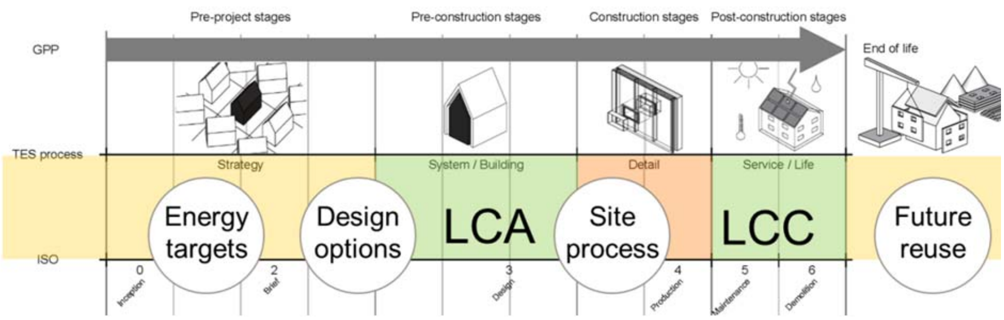


Figure 2-1 Life cycle process for integrated retrofit solutions using TES (le Roux, Ott)

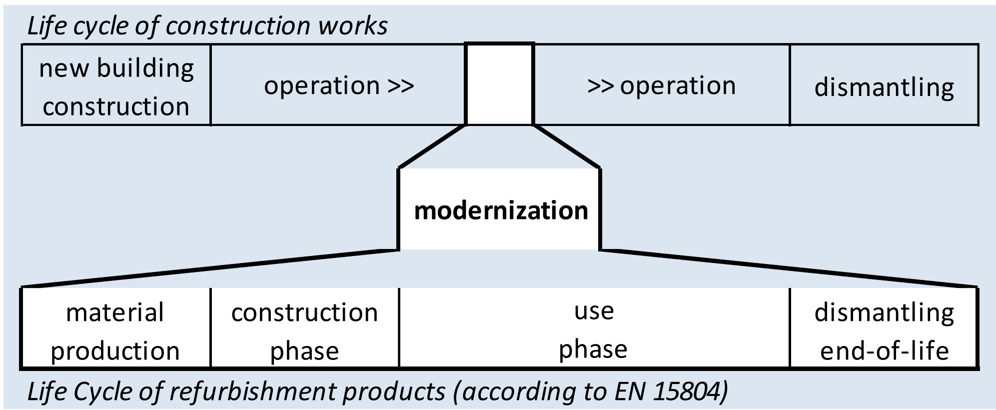


Figure 2-2 The life cycle of refurbishment products such as TES compose of just one part within the Life Cycle Analyis of construction works on the building level (Ott)

2.1.3 **Life Cycle approach to modernization**

The LCA of an energy efficient retrofit may not be disregarded, even when the energy-related rehabilitation of a building has a goal to reduce greenhouse gas emissions related to building operations. Under the economic pressure to make the lowest possible investment for the maximum energy saving effect, the primary energy use and the global warming potential from production, as well as possible risks or hazardous material burdens in production, processing, use and disposal phases can have a negative influence on overall sustainability targets.

Nowadays measures and methods of refurbishment and retrofit are resource intensive with impact on the environmental sustainability. Energy efficiency actions aim at decreases of operational energy per year of 20-50 % following the regulation. The necessary bundle of methods requires resources and energy and leave the retrofitted building with an enlarged carbon-footprint.

There is a notable change in ratio of carbon-footprint to operational CO2-emissions of energy efficient buildings [9].The ratio for old, existing buildings was often stated as 20:80 throughout a full lifecycle of 50 years. In new, energy efficient construction it is 60:40 and will further change [10].

A passive house level with a reduction of factor 10 in energy consumption might show positive results during operation phase but cause a larger footprint in production and erection phase. Finally end of life should not be forgotten and still contributes to carbon footprint during actual refurbishment, in future actions and at end of life. The environmental impact of an increased material consumption is not only related to the carbon footprint. It causes damages to the environment on several levels; fresh water consumption, acidification, ozone layer depletion should exemplify that negative potential.

The path to energy efficient dwellings shifts the perspective towards the material balance of buildings, which was not on the agenda before [11]. It was found that embodied energy and carbon of buildings has a strong material extraction and production related impact but also the method of construction influences the full *module A* environmental balance of building production.

2.1.4 **EN 15978 building system level**

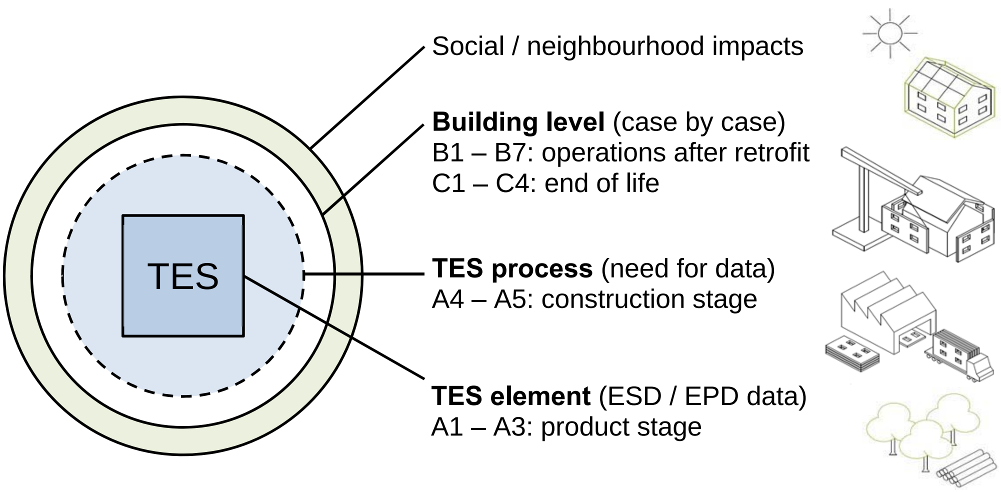
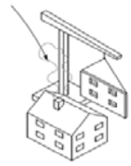
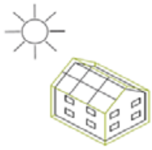
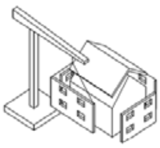
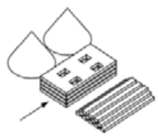
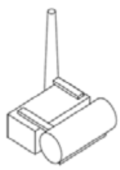


Figure 2-3 System borders and life cycle stages on building and product levels (Ott, le Roux)

Table 2-1 TES Life Cycle concept with phased impacts and benefits (le Roux)

	Life Cycle stages	COST	ENVIRONMENT	SOCIAL	TES BENEFIT
	PRODUCT	**UPSTREAM LOSS**			**PRODUCT EPD**
A1	Resource supply	supply cost increase	resource depletion	working conditions	Forest management
A2	Transport	fuel costs	emissions	traffic safety	Logistics
A3	Production	procurement	hazardous waste emissions	regional employment	Upcycle
	CONSTRUCTION	**OVERHEADS**			
A4	Transport	transport costs	noise pollution	traffic safety	Delivery
A5	Assembly	professional fees labour costs temporary site works cost of site landscaping	site disturbance pollution	Corporate Social Responsibility (CSR) On-site facilities Stakeholders involvement Residents disturbances	Prefabrication
	USE	**CONSUMPTION**			
B1	Use	changes in use fit out	Performance assessment	Suitability for use Accessibility Heath, safety and comfort Security and safety Infrastructure and services Social Affordability User control systems Aesthetic quality	Performance monitoring Control systems
B2	Maintenance	Management Insurance and tax Cleaning Unpredicted costs	Commissioning	Maintainability	Construction quality Core vs. cladding
B3	Repair	Damages	Robustness vs. waste	Heath and safety risks	Durability
B4	Replacement	Resale Part failure	Modularity	Serviceability and adaptability	Component replacements
B5	Retrofit	Devaluation Redundancy Modification in use Subsidies	Product impacts Construction impacts	Stakeholders involvement Social Affordability Design for disassembly	Added service life
B6	Energy consumption	Exposure to costs	Global warming potential	Cost efficiency	Renewables
B7	Water consumption	Utility risks	heating potable water	User control systems	Cost savings
	END OF LIFE	**WASTE**			
C1	Demolition	Obsolescence Clean up	Pollution	Accident risks Dust, noise	Extended service life Design for disassembly
C2	Transport	Added costs		Traffic safety	Waste streaming
C3	Waste	Waste sorting	pollution	Hazardous materials	Materials flow
C4	Landfill	Landfill costs	pollution		Upcycle
	CREDITS	**BURDENS**			
D	Reuse, recover, recycle	Replacement	Disuse		Reuse
		Lost revenue Land sale New purchases	Misuse Abuse Refuse		Recover Recycle Raw material
	EN 15978	*EN 15643-4*	*EN 15643-2*	*EN 15643-3*	***EPD (EN15804)***



2.2 Retrofit Process design options

2.2.1 Early stage design effort

The right metrics in sustainability is hard to achieve and the retrofit often offers dilemma of the embodied versus the operational greenhouse gas emissions.

While the main focus of retrofit is the final result with an optimal solution for operational performance the process of retrofitting remains underdeveloped up to now. This is seen critical by the authors due to the fact that a retrofit is much more than planning a new building without tenants involved. Within existing sustainability assessment systems the field of retrofit and refurbishment is fairly low developed. Various pre-checks of rating systems with real cases and with alternative methods rise different aspects worthwhile to consider in a benchmarking. These criteria range throughout economic, environmental and social criteria benchmarks of sustainability in construction and are not considered by any of the existing systems. As part of an advanced decision making process in retrofit of existing buildings a whole set of information is required additionally to energy metrics. SmartTES proactively deals with all sustainability aspects and discusses interrelations between different criteria and life cycle phases under the overall goal of reduction of carbon emissions when the building is under full operation.

Figure 2-4 Illustration of different quality levels of retrofit, starting with the existing building top left up to a total refurbishment including extensions. Image is taken from the Retrofit Advisor (Zimmermann [12])

2.2.2 TES integration with solutions for energy retrofit

Table 2-2 Example scenario of analytical parameters with existing conditions and proposed retrofit measures (after Ott)

	Parameter	Existing	Measure	New Quality
Legal conformity	Fire safety	-	Conformity	+
	Energy efficiency	-	Improvement	+
Urban integration	Density	-	Extensions	+
	Site ecology	-	Enhanced	+
Technical quality	Envelope	-	Insulation	+
	Building services	-	Replaced	+
Functional quality	Floor plan	-	Renovated	+
	Circulation	-	Lifts	+
Social and cultural quality	Accessibility	-	Barrier-free	+
	Indoor environment	-	Heat recovery ventilation	+
Ecological quality	Material durability	-	Reuse	+
	Demolition waste	-	Sort and recycle	+
Economic quality	Maintenance	-	Cladding	+
	Income	-	Upgrade	+
Alternatives/ Trade-off	Existing heating	-	Renewables	+
	Short life span	-	Extended	+
	On site	-	Off-site	+

2.2.3 **Regional climate adaption of TES**

Another level of performance targets is related to technical specifications of TES and construction detailing. These targets influence the product itself and will make it a safe and durable construction product. Climate related risks of a TES retrofit are dealt within smartTES WP6.

Other risks closely related to climate and building physics like window improvement, construction detailing, fire safety or multifunctional TES components are discussed in work package one. The result is that all these different topics are solved for their own specific requirements. They follow the prescribed risk level of the building code and the actual technical knowledge. On the other hand the solutions are discussed with the experts from other work groups to avoid interferences and contradictory results.

The technical risks are reduced by this approach of intensive discussion of overall solutions and the fulfilment of specific performance requirements. Other overall risks are mostly related to a project with specific conditions and have to be assessed in the pre-design phase or the project development as well as later on in the planning phase and work preparation for prefabrication.

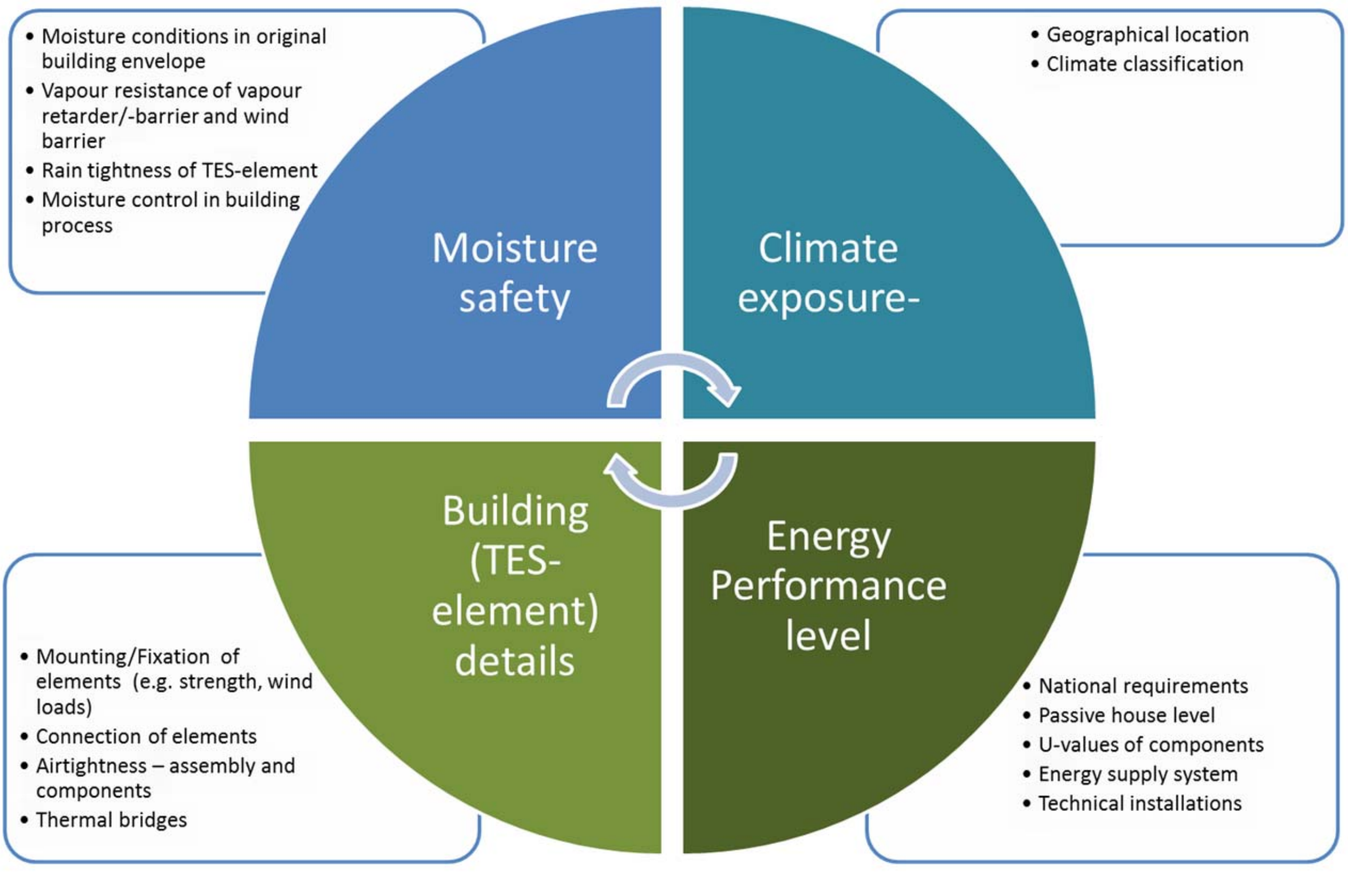


Figure 2-5 Robust design principles for smartTES retrofit (SINTEF)

2.3 Impacts, Risks and Benefits of Energy Retrofits

2.3.1 Overcoming obsolescence

Obsolescence is a real business risk for building owners, with possibilities of asset vacancy, rent loss, and the decrease of market value on the urban level (**Figure 2-7**). Risk for society goes parallel with building obsolescence, such as risks to personal comfort and human health, low productive working environment, and downfall or ghettoization on the urban level. Furthermore it is a risk for economy and hurts society and owner. Risk for environment is related to the loss of built and urban space that can end in demolition and waste piles or a massive construction with resource demand (**Figure 2-6**). The energy efficient refurbishment of existing dwellings has to be observed particularly from a life cycle point of view. The primary energy inflow for refurbishment is predicted to be higher, than the outflow from dismantling and the cumulated energy savings over a certain amount of time. The reason will be the building performance indicators to fulfill regulations along with demand.

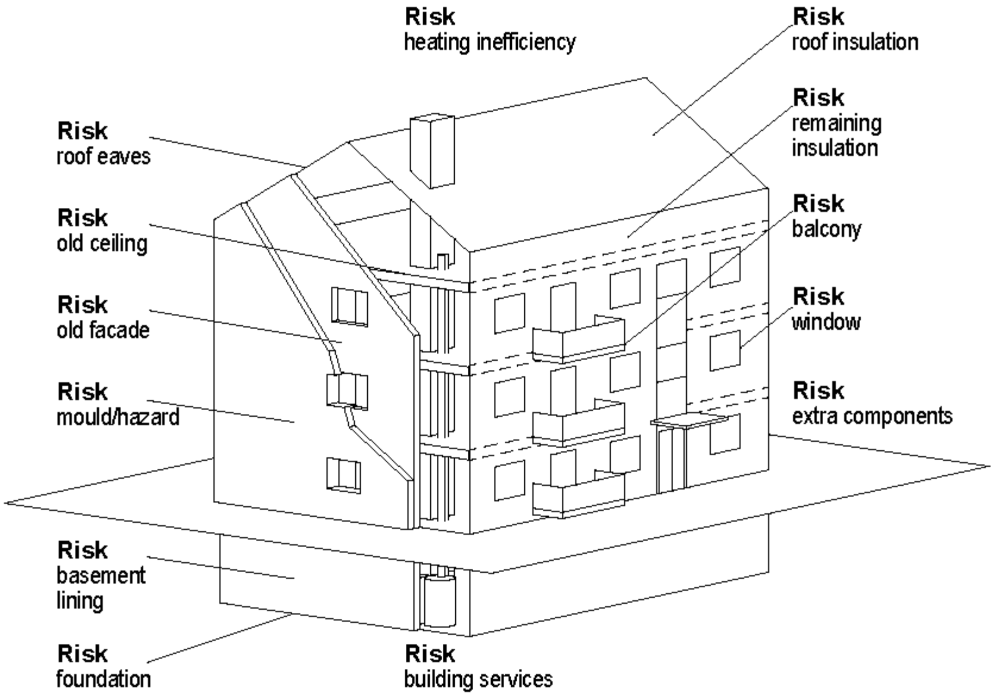


Figure 2-6 Overview of risks retrofitting existing building system (Ott)

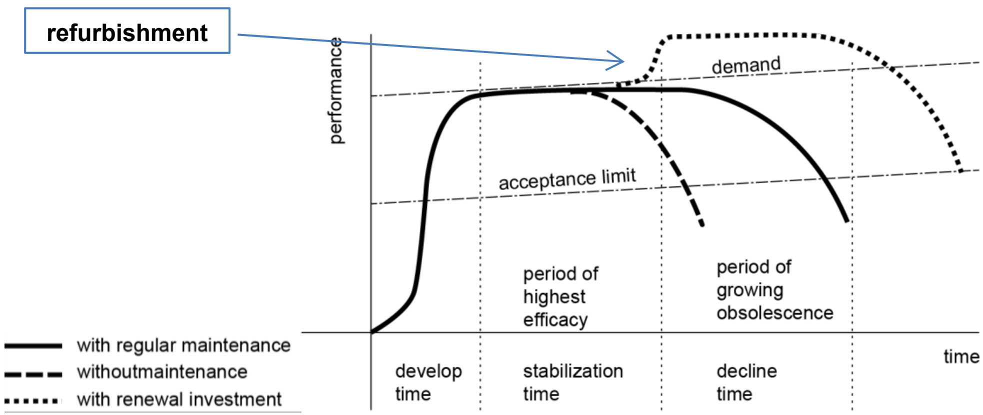


Figure 2-7 Obsolescence, use time and performance (Thomsen)

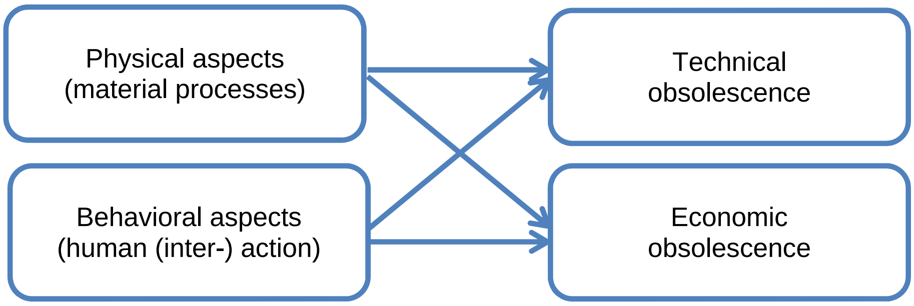


Figure 2-8 Causes of obsolescence (Thomsen)

There are several risks for doing refurbishment and deep retrofit that interferes with the physical and behavioral aspects of dwellings, (Thomsen & van der Flier 2011). To overcome technical obsolescence measure are necessary to improve the physical quality of the building. The technical performance of the building is very low at this stage.

Therefore it is necessary to increase performance. This is practically done by interruption of visible and invisible aging processes or retrofit of deteriorated physical parts and components.

Very often the economic obsolescence forces measures to overcome crisis. This is often related to market position of the property when return on investment drops due to lacking rent ability. There are measures to improve the behavioral aspects like changes in clearance of social problems.

When the obsolescence is far advanced and the profitability suffers, measures should be taken. They can relate to, for example, changes in the use and function of the building but also improve the technical performance. Often, a bundle of measures is needed to achieve a cost- and resource-efficient solution. These measures are also connected to a conformity inspection of the building rights, whereupon additional resources might become necessary.

Sustainable refurbishment of the building stock is a logical part of the whole puzzle. It outclasses the property and creates longevity resilience.

The material outflow and inflow has to be paid back over a decreased time span whilst operation. It can offer an appropriate way of solving the dilemma between carbon-footprint and CO2-emissions by reusing as much as possible of the already embodied energy of the stock. When the building life cycle is prolonged, its embodied energy will not be destroyed in demolition anymore but is used in a more intelligent way than today. Nevertheless requires such a scenario conversion to a more efficient operation of the dwelling by retrofitting the building performance. The SmartTES can provide a conversion method with a sustainable perspective by prolonging whole systems life cycle. This solution takes care of the refurbishment and dismantling phases of a dwelling, and reduces carbon footprint by intensive renewable materials use, basic requirements of environmental sustainability.

2.3.2 **Condition analysis and risks**

On the client/owner side there is a lot of concern about the risks of refurbishment – how is the impact of conventional refurbishment systems on buildings, their appearance and indoor climate. What is neglected up to now is the environmental burden by need of immense material masses. Each of these issues influence residents as well as the society. The TES method provides a holistic solution. The dilemma is that clients facing results from obsolescence discussion, and decline of return of investment, clients are not able or not willing to take further risks for refurbishment. In order to overcome obsolescence substantially they have to decide on deep retrofit measures.

This decision influences the group of residents, who can be owners as well. They face risks from the refurbishment actions themselves or for their property.
If there is no solution who addresses the concerns of residents the risk to succeed various profound actions is higher.

SmartTES addresses several social sustainability topics and has positive solutions to tackle the risks related to them. But there are still uncertainties which are method related and other which are valid for all refurbishment methods as it is shown in the following list.

Risks of retrofit

1. Uncertainty about cost is related to the risk of a negative cost-benefit balance; the risk is for the client!
2. Uncertainty about the precision and risk of perfect fitting façade; risk is for the contractor, but influences the client and the tenants. This was dealt with in TES EnergyFacade and demonstrated in several projects.
3. Uncertainties about the construction related to the risk of mould and durability as well as fire safety (valid for other methods as well); risk is at contractor and partly at the clients and tenants! Appropriate climate construction and fire safety is dealt with in SmartTES
4. Uncertainties about the assembly process. Lessons have been learned from the ongoing demonstrations: and there is a high potential of improvement.
5. Uncertainties about building service systems integration and the risk of feasibility on the technical / product level of TES; risk is at the contractor (SmartTES proposes feasible solutions and has documented successful demonstrations) and influences clients and tenants when it does not work properly.
6. Uncertainties about the environmental impact of TES on product level, energy savings on building level and the long term behavior (both levels) is related to the risk of environmental burden; risk is at the client (influences the property value) and the society (influences our habitat).

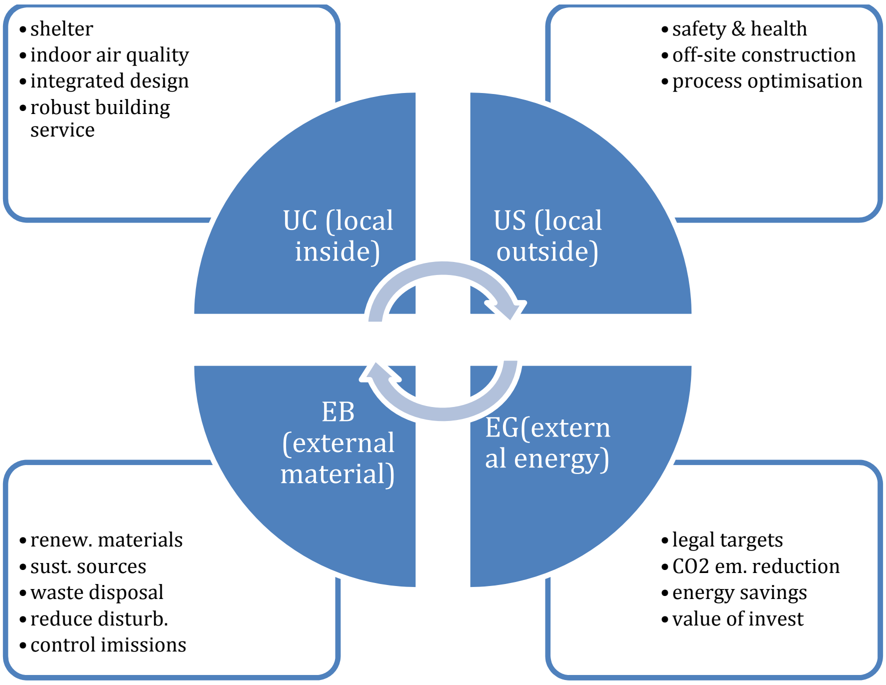


Figure 2-9 Risk areas. UC= user comfort, US = user safety, EB = environment burden, EG = energy goals (Ott).

Sustainability potential risks
The following risk categories are to be considered in the energy-efficient refurbishment and retrofit, indoor air quality which is part of user/resident comfort (UC), user disturbance which is part of user safety and health (US), material resource depletion and environmental burden of refurbishment action on a global level (EB), and reducing harm to global environment by reaching energy goals (EG) (**Figure 2-9**). The risks must be reduced to bring them more in line with the sustainability criteria. In particular, the categories belonging to social and material-ecological area are post-retrofit oriented. This means in conventional day-to-day business optimization of the operational phase is paid for by high resource demand and costs.

Risk potential resource depletion (RD)
The material flow as a basic concept of ecologic footprint quantification should provide a deeper insight in the input and output balance of the retrofit phase of case studies. Mass flow analysis is the basic concept to analyses the ecologic footprint of a project besides the energy consumption in operation. Therefore the refurbishment phase, that consist of a construction phase in building life cycle as well as a demolition phase, has to be balanced for its primary energy demand. The outcome than can be compared with the operational phase and building's primary energy demand after refurbishment. The high performance requirements of the energy performance of buildings directive set high targets for low energy consumption also for the retrofit of the building stock (EC 2002). The fact of high planned operational efficiency in building's future, raise the question of the share of resources needed for other phases in buildings life time. For the basic concept of material flow analysis: see Eyerer [13] and Kiel [14].

Examples of specific risks

User Comfort: Central goal of each building is an optimal user comfort, in dependence of the use of the building. Protection from climatic extremes is a fundamental principle of each shelter. The better and the more constant the indoor climate the wider and more complex is the range of parameters which influence e.g. indoor temperature.

Integrated design is necessary to deal with the complexity and optimizes it towards a robust solution.

Indoor Air Quality (IAQ) is a prioritized topic in modern and refurbished buildings. The improved airtightness of the building envelope leads to a higher concentration of air pollutants in the living areas and that can cause discomfort and a health risk in user safety.

The Indoor relative humidity (IRH) level should be appropriate according to the use of the space. Additionally there are physiologic recommendations, valid for domestic homes or offices for example. The relative humidity of the ambient air is ideally set, from a physiological perspective, between 45 - 50%; it should not be less than 40% and not exceed 70% due to the risks of accumulation of moisture in construction parts.[15]

Damage sensitivity can be related to high humidity on the basis of the following parameters:

- residents behavior (moisture production) - basic constant
- user behavior related to ventilation (moisture dissipation) - does not change (traditional behavior)
- sorption of surfaces (moisture buffering) - can be changed (painting)
- technical properties of the envelope (airtightness, heat bridges) - solved by SmartTES
- indoor temperature - stable
- outdoor temperature - no influence = climate dependent
- outdoor air humidity - no influence due to climate

Risk of different refurbishment scenarios with a focus on hygrothermal and ventilation related risk.

Existing buildings lack proper heat and moisture safety that raises the risk of damages to construction as well as to residents. Safety measures are sufficient insulation and air tightness of the building envelope. In energy efficient refurbishment these measures are one of the most important tasks:
Scenario 1: conventional refurbishment/retrofit of the envelope (also partial)
Scenario 2: Refurbishment of building services systems only
Scenario 3: SmartTES deep retrofit also includes building services systems

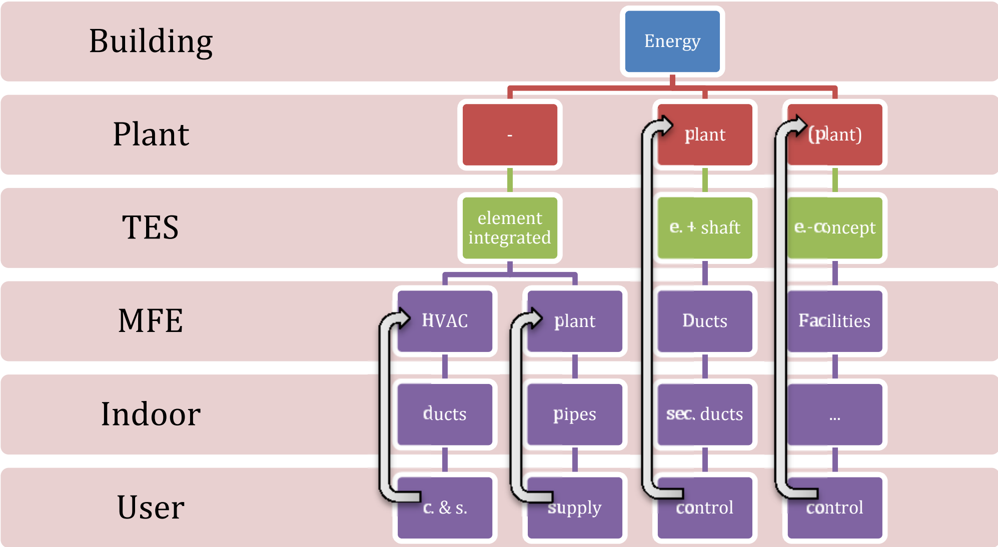


Figure 2-10 Breakdown structure of different scenarios in line with the multifunctional envelope concepts (Ott)

Table 2-3 Reasons for hygrothermal deficits and mould:

	envelope related	building services related (heat energy supply)	affected constructions
material heat bridges	+	-*	concrete ceilings, columns
construction heat bridges	+	-*	balcony, lintel, parapet
geometric heat bridge	+	-*	corners, reveals
convection (leakage)	+	-*	joints, cracks
diffusion	+	-*	
material moisture	+	-	
surface temperature	+	+	
rel. humidity + air temper.	-	+	
* (could be influenced by room heating)			

Table 2-4 Synopsis of SoA operational vs. process and environment goals from BNB criteria

Operation phase		Process and Environment	
+	ENV 1.2 Primary energy operation	-	ENV 1.1 Local / Global Environment
○	SOC 3.1 Health	-	ENV 1.2 Primary energy material
+	SOC 3.2 Functionality	○	ECO 2.1 Value preserving
○	SOC 3.3 Design	-	PRO 5.1 Planning
-	TEC4.1Technical operation	-	PRO 5.2 Construction works

2.4 Retrofit Material Flow Analysis

2.4.1 TES performance targets

There are hardly any sophisticated systems in existing sustainability ratings for the modernization. Preliminary checks, performed on various projects and evaluation systems using real case studies draw attention to core indicators, which are important for the benchmarking of measures. These include general economic, environmental and socio-cultural characteristics. The aim is a comprehensive picture of information in addition to the energy performance certificate, required for decision-making in terms of sustainable development of renovation results. With the inclusion of this information, decisions can be made on a broad data base. It remains in the foreground, which measures most effectively contribute to the reduction of CO2 emissions. In the future constructions must be dealt increasingly on resource scarcity in the markets and efficiency demands of the EU.

The missing life cycle analysis is identified as a vulnerability of modernization. The modernization process is accompanied by significant environmental impacts and further developments for its optimization are missing. Both together are contrary to the principles of sustainable planning and sustainable development. While new buildings is already trying the holistic view of the entire life cycle of a building is a paradigm - the existing buildings are only reworked for most efficient use phase and neglected other key indicators of sustainability. Towards holistic consideration the BNB system for the certification of federal buildings provides a first step, tuned to develop modules on the building life cycle assessment.

Fulfilling the requirements for energy efficiency retrofits requires additional material effort. Overall, the effort to reach a new energy standard is higher than the gains of urban mining. The energy demand from heat transmission through the building envelope is significantly reduced after the retrofit, but the effort in material related primary energy is many times higher than the annual transmission energy savings.

The evaluation of the TES method according to BNB criteria (**Table 2-4**) shows the inadequate fulfilment of criteria in the field of ecology and process-related criteria. Especially the latter are important when modernised during operation, which is the normal procedure. This leads to the poor implementation of modernization processes from the perspective of sustainability, which is tried to be counteracted by the TES method.

Table 2-5 Key performance indicators for retrofit benchmarking and decision making.

Energy after	**Energy before**
Operation primary energy GHG operation Resource primary energy GWP resource	Operation primary energy GHG operation
	Land Use
	Change of land use Access to service
Construction	**Materials**
Waste generation Safety	Resource consumption Materials and non-renewable energy
Building Services	**Users**
Indoor conditions and air quality Maintainability and serviceability	Adaptability Safety

2.4.1 Inputs and outputs

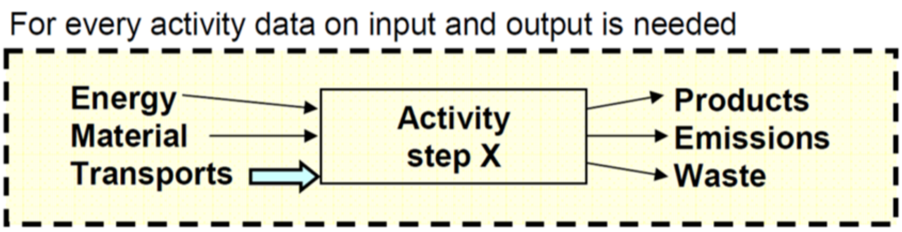


Figure 2-11 LCA Inputs and outputs associated with assessed activities

2.4.2 Mass balance of material flow

The material flow as a basic concept of environmental impact quantification provides a deeper insight in the input and output balance of the retrofit phase of case studies. Mass flow analysis is the basic concept to analyze the ecologic footprint of a construction. Therefore the refurbishment phase, that consist of a construction phase in building life cycle as well as a demolition phase, has to be balanced for its primary energy demand. The outcome than can be compared with the operational phase and building's primary energy demand after refurbishment.

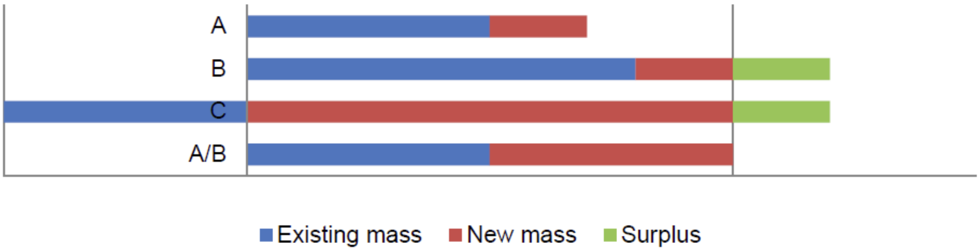


Figure 2-12 Examples of mass distributions in retrofit scenarios. The benchmark is new build (C) which can be exceeded by surplus investment (Ott)

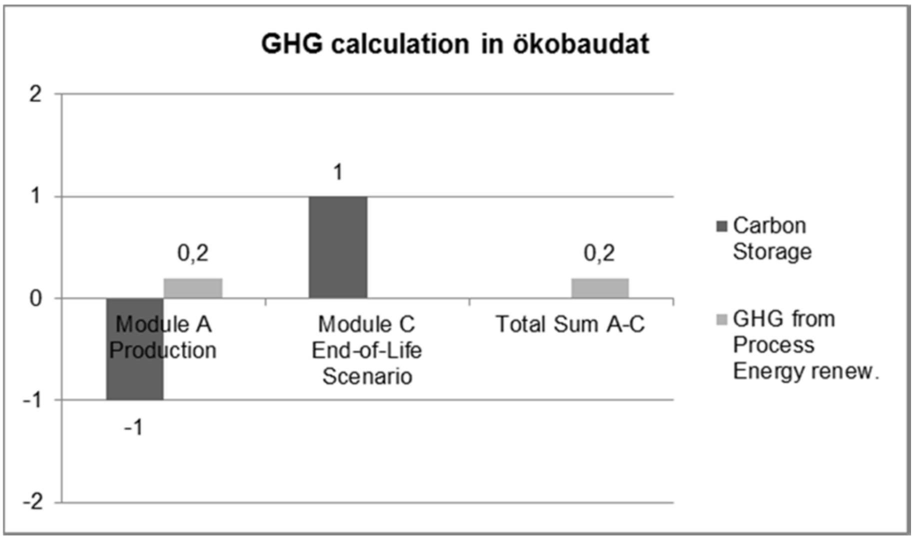


Figure 2-13 Greenhouse gas allocations compensated with carbon storage (Ott)

2.5 TES retrofit case studies in material flow

2.5.1 General methodology of embodied energy calculation

The evaluation concentrates on mass flow analysis in case of an extensive refurbishment. Its aim was the analysis of material flow which was generated by the refurbishment concept of partial demolition, possible extensions like new attic floor, redesigning the floor layout, circulation and improving the building envelope with additional insulation. Based on plans, elevations, typical sections, pictures from the demolition and construction works, the measures of retrofit were retraced, analyzed, calculated and finally balanced. After combining these balances with environmental data, it was possible to obtain information about environmental impacts caused by embodied primary energy and related carbon emissions.

All data of the construction is depicted from design and detail drawings and is supplemented with photos and sketches from the construction site. The mass calculation and allocation is done in calculation sheets.

The data for the environmental impact is available from the German database Ökobau.dat. It contains generic LCA data with source and year of generation which were aggregated from industry data. Since a short while the database also contains environmental product declarations (EPD) data from specific products of one producer as well as aggregated EPD from industry associations of producers of a standardized product. The main data in the Ökobau.dat covers the life cycle inventory and the life cycle impact. These categories are calculated from cradle to gate. The Ökobau.dat also covers end of life information for a reasonable amount of items in the database. That information will be processed for the waste management from demolition works on the existing building.

2.5.2 GWG Munich, apartments

Figure 2-14 Process of change from original building, refurbishment site process, to end result GWG Munich (photos GWG archive, le Roux, Ott)

A total retrofit of the existing, obsolete Munich dwellings was task of the design and planning. The building performance after retrofit should reach a low heat energy demand of 31 kWh/m²a, according to design calculations, that is around 35 % better than the standard. The overall energy standard shows a primary energy consumption of 24 kWh/m²a. This number is lower than the heat energy demand, because it includes the bonus for regenerative energy sources like solar thermal collectors and a primary energy factor of $f_p = 0.7$ for district heating.

The refurbishment concept contains a heavy dismantling of the existing dwellings. The construction was stripped down to the primary structure of the building. Additional changes in floor plan layout and new circulation cause interventions on the interior walls as well as on the window openings. A new attic floor and a roof were added as well as an entire new building envelope made from TES EnergyFacade elements.

Outflow

An extensive intervention takes place in the existing construction in GWG case study. Apart from the change of the facade it deals with the dismantling of the roof, the demolition of the staircases and the entire reorganization of the interior space. Therefore the building is totally gutted. The dismantling waste has to be recycled or landfilled. The outflow diagram **(Figure 2-15)** illustrates the mass allocation of the entire demolition works. High amounts fall to share of masonry (from exterior and interior walls), concrete (balconies, stairs), render and gravel (former flooring construction). The related absolute embodied primary energy not renewable (PENR) indicates the highly processed mineral construction materials. The organic, renewable resources mark the high share of embodied primary energy content renewable (PERE). The renewable share is conserved in recycled products or relieves fossil energy if it is used thermally. The non-renewable mineral resources could be recycled as well, the landfill option leads to its loss.

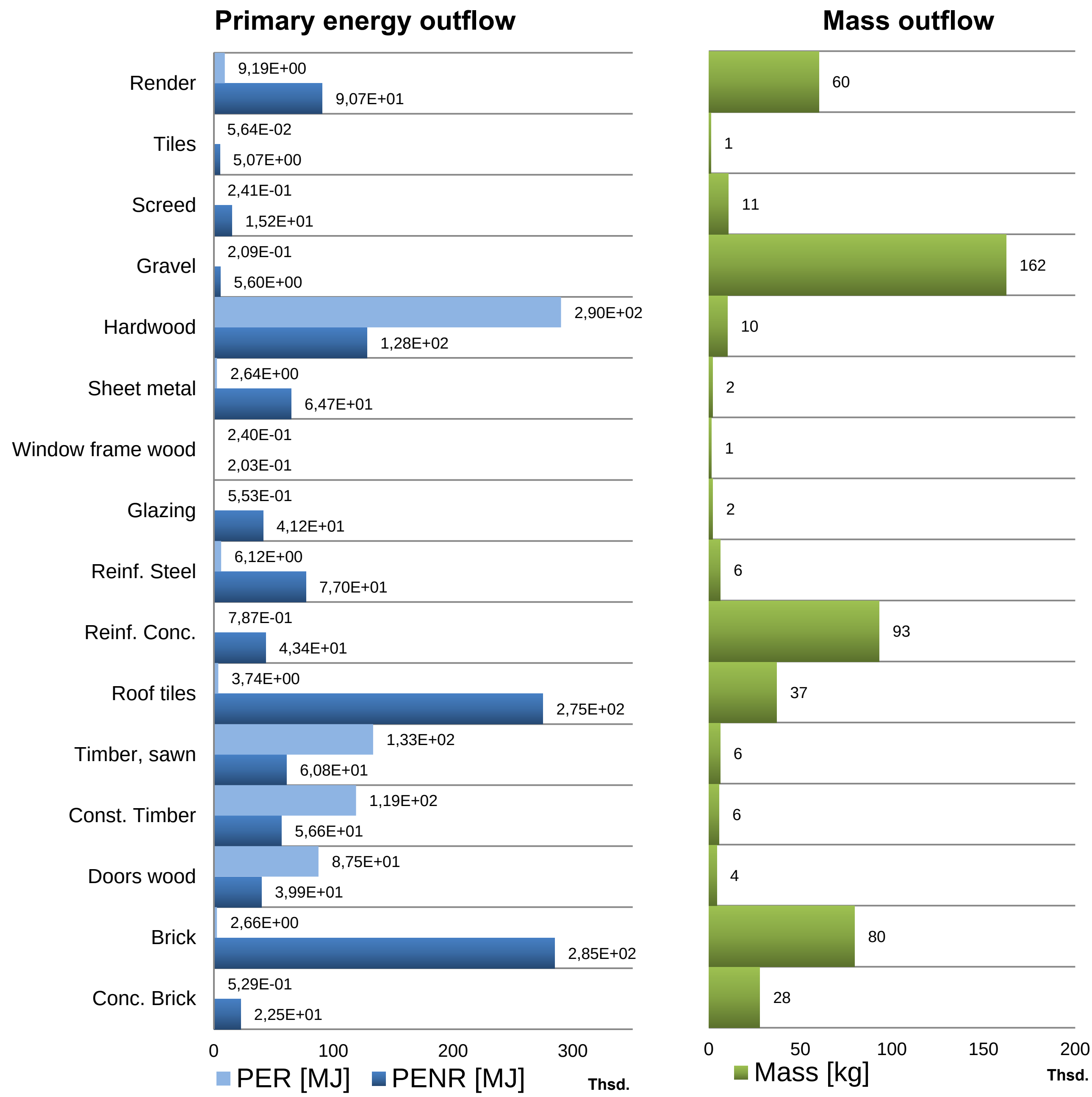


Figure 2-15 Case study GWG Munich: Primary Energy content for production: PE outflow balance from dismantling based on Ökobau.dat 2009 (Kiel)

End of life
The end-of-life scenario for the demolition waste is according to national rules. These rules are quiet new and were developed in the course of the introduction of the German DGNB/BNB sustainability assessment schemes. The scheme currently simplifies the end-of-life scenario, due to the lack of data for this phase. There are five different scenarios for demolition waste treatment at the moment. The following material classes have to be separated in the calculation due to these scenarios:

1. Metals (100% recycling)
2. Mineral based construction products (mostly recycling)
3. Material with a calorific value (e.g. timber, plastics, etc.; will be used thermally)
4. Heat generation systems and technical equipment (own EoL data sets in Ökobau.dat)
5. All other materials, which are allowed to be landfilled.

The end of life scenarios for the GWG Munich case study (**Table 2-6**) shows groups of materials according to their end-of-life scenario. All dedicated mass values are multiplied with the corresponding PE values for each disposal scenario. The total amount shows a primary energy bonus by a negative value. Recycling or thermal use of resources gives this bonus because it replaces an existing source of energy. Finally it is an energy that is released by waste incineration and fed into the grid, and this energy is conserved at another place.
A few material groups are reused for energy purpose or for recycled material use. Hence it turns the balance into a positive direction. Consequently the outflow of demolition waste brings a gain in primary energy in total amount.

The inflow diagram (**Figure 2-16**) is the counterpart to the outflow amount. It is necessary for the upgrade of the building performance with all necessary technical and functional properties. The prognosis for the inflows is predicted to be higher than the outflow, because the building performance is meant to be higher than in the old construction. This requires a higher input and a bigger amount of embodied primary energy.

The inflow illustrates the main input on the mass side of resources. The main input takes place in masonry, concrete, screed and render. Mass figures are also multiplied with primary energy figures from the Ökobau.dat database. Analogue the results of the outflow, the primary energy content of all the mineral based resources show high amount of PENR proportional with their high mass. The renewables have high values of PERE. It increases also proportional but with a lower rate due to the lower specific density of the renewables.

Furthermore it is obvious that the diagram shows very high numbers for PENR of insulation material based on mineral wool, solid construction wood, 3-layer-insulation glazing and the impact sound insulation. The high figures can be explained by the high amount of material which has only low and medium bulk density hidden in mass balancing. Glazing shows also very high values of PENR that results from the high amount of primary energy needed for the production of float glass.

The input of resources from the Ökobau.dat database only provides cradle to gate values. The analysed data of new built construction covers only the life cycle cradle to gate. The impact of construction work, transport etc. is not contained yet.

Table 2-6 Case study GWG Munich: End of Life scenarios according to German Ökobau.dat 2009 (Kiel, Ott)

End of Life Processing	**Material**	**Mass** [kg]	**Output** PE [MJ]		**Recycling potential according to Ökobau.DAT** PE [MJ]		**GWP** [kg CO2-Equiv.]
			NR	**R**	**NR**	**R**	
Landfill (partial recycling possible)	Cement block	27.720	22.481	529			
	Concrete	93.045	43.628	791			
	Screed topping	10.680	15.166	241			
	Plaster render	60.033	90.650	9.185			
	Ceramic tiles	2.136	10.680	112			
		193.614	**182.605**	**10.858**	**30.978**	**2.052**	
Recycling	Reinforcing steel	6.211	77.015	6.118	-72.668	-78	
	Sheet metal	1.998	64.722	2.637	-25.369	-118	
		8.209	**141.737**	**8.755**	**-98.037**	**-196**	
Recycling possible	Glass	2.160	41.143	552			
	Gravel fill	162.336	5.601	209			
	Brick	79.547	284.778	2.555			
	Roof tiles	37.014	275.010	3.738			
		244.043	**331.522**	**3.316**	n/a	n/a	
Thermal use	Mixed timber	10.475	100.750	220.563			
	Construction timber	5.500	56.584	118.800			
	Wood window frames	1.445	203	240			
	Oak hardwood floors	10.146	128.022	290.074			
		27.566	**285.559**	**629.677**	**-283.928**	**-4.273**	**32.528**
				Sum:	**-350.987**	**-2.416**	**32.528**

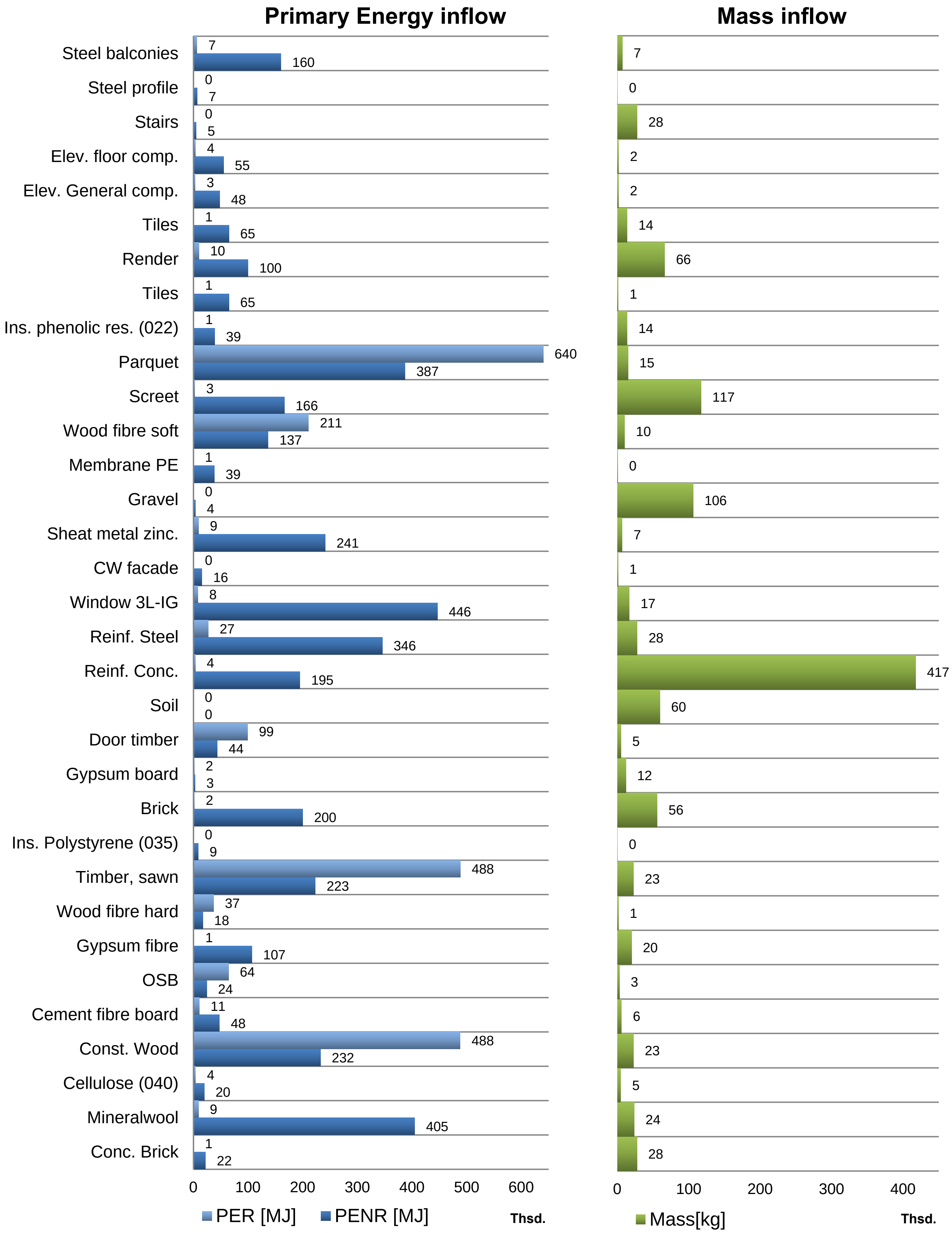
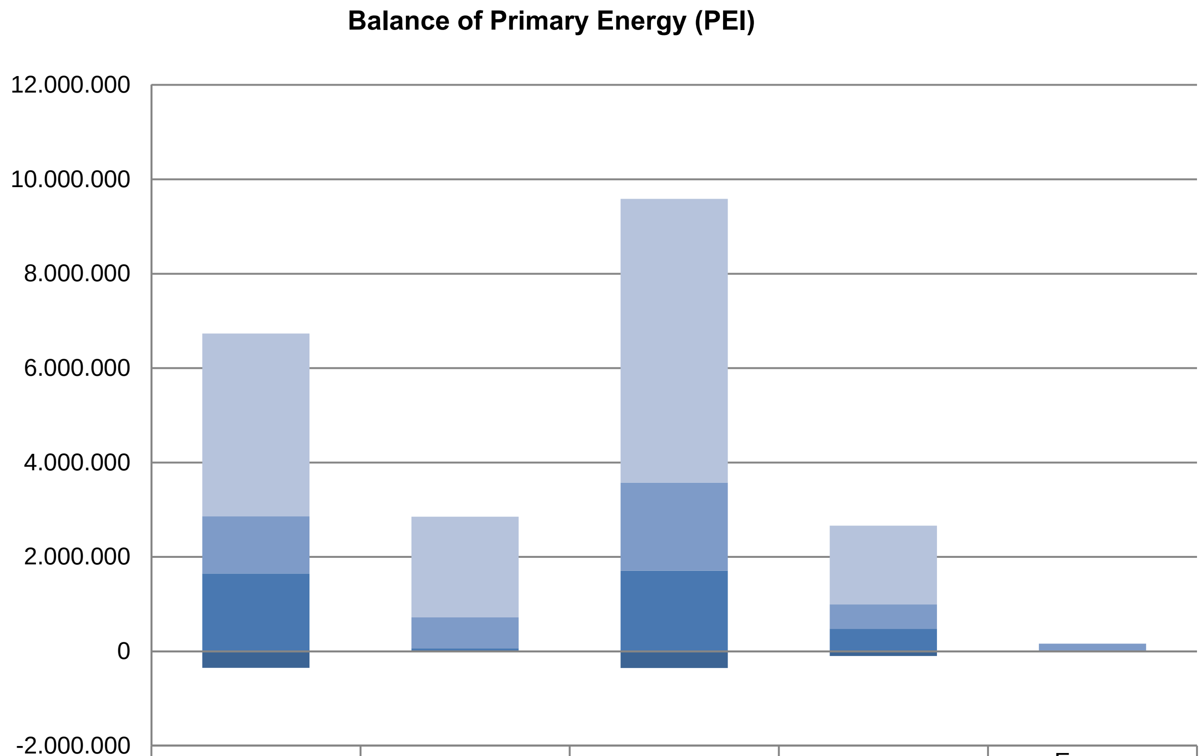
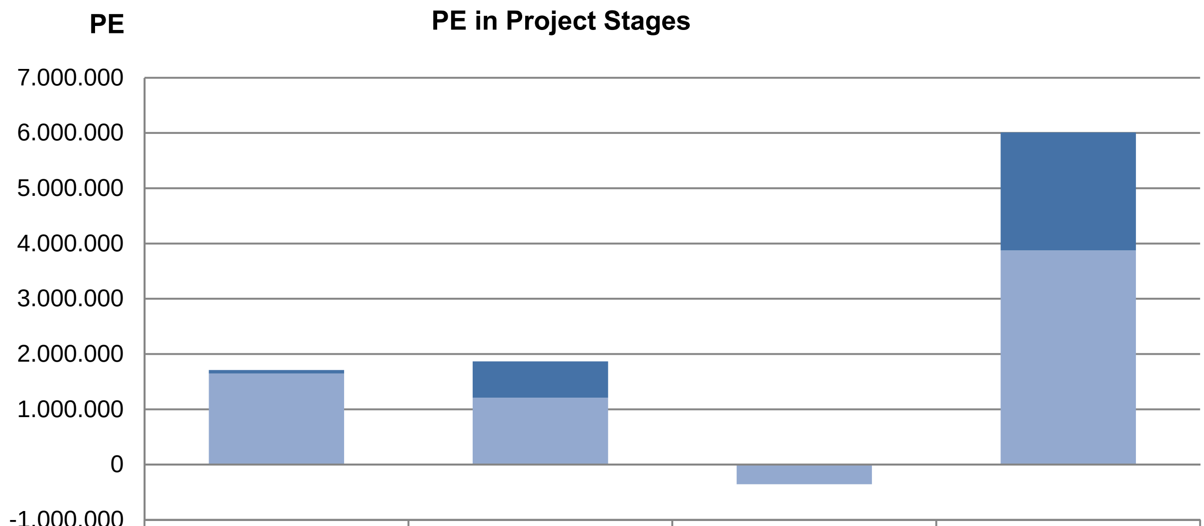


Figure 2-16 GWG Munich: Primary Energy content for production (PE): Inflow balance PE from refurbishment based on Ökobau.dat 2009 (Kiel, Ott)



	PENR [MJ]	PER [MJ]	Total PE [MJ]	Total [kWh]	Energy saving/year [kWh/a]
IN (after retrofit)	3.875.063	2.136.002	6.011.065	1.669.740	
OUT (before retrofit)	1.210.622	656.397	1.867.019	518.616	161.159
EoL/Recycling	-350.987	-2.416	-353.403	-98.168	
Remaining	1.648.112	61.139	1.709.251	474.792	

Figure 2-17 Case study GWG Munich: Total mass flows of retrofit activity (Kiel, Ott)



	Remaining	OUT (before retrofit)	EoL/Recycling	IN (after retrofit)
PER [MJ]	61.139	656.397	-2.416	2.136.002
PENR [MJ]	1.648.112	1.210.622	-350.987	3.875.063

Figure 2-18 Case study GWG Munich: Balance of renewable and non-renewable Primary Energy (PE) through all steps of the retrofit, including the end-of-life for demolition (Kiel, Ott)

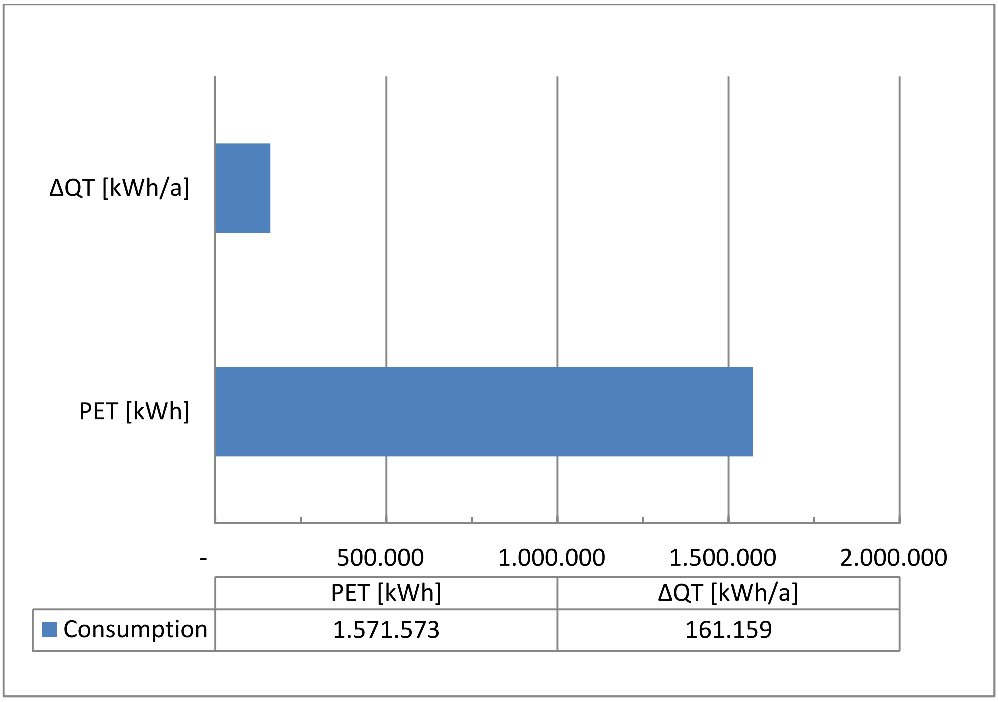


Figure 2-19 Annual heat energy demand compared with total primary energy content (Kiel, Ott)

2.5.3 **Realschule Buchloe, school**

Figure 2-20 Process of change at Realschule Buchloe from original building to end result with TES facade (photos Ott)

The refurbishment concept contains a heavy dismantling of the existing building envelope of the school. There are precast concrete balconies which run around the entire building envelope as escape and maintenance facilities on each floor level. These balconies are heavily damaged and have to be demolished either. The construction was stripped down to the primary structure of the building on its exterior leaf. The interior surfaces (ceiling and flooring), the heating and ventilation system and technical equipment (lighting, electrics, ITC) will be refurbished in a second step. These measures are not calculated for this examination. The roof was already refurbished two years ago, therefore it was not touched.

The case study examines the entire facade of the school building. Further system borders of the school building exclude the roof, the interior, the construction of the basement. It includes the ceiling above the basement and the foundations of the new envelope.

Outflow

The demolition and dismantling process removes two main components from the façade. The cantilevering concrete balconies are lifted and cantilevering support is cut off the main structure. Additionally the bracket-mounted concrete sills and lintels are demolished. The existing aluminum windows which are mounted between the remaining interior concrete sill and the ceiling are dismantled. They have a two layer glazing and opening window frames. The interior sill cladding was removed during the interior refurbishment.

The biggest mass is related to the demolished concrete components with roughly 300 tons (**Figure 2-21**). All other material weight is relatively low and between one to 25 tons. The peaks of non-renewable primary energy content are shown for aluminum windows and 2-layer glazing. The distribution of PENR is on a similar level for concrete, reinforcement steel, steel grilles and sealing, ranging between 120.000 and 180.000 MJ. The PERE is very small in all demolished construction except from the aluminum windows, with 200.000 MJ worth mentioning.

End of life

The input balance of the school refurbishment (**Figure 2-22**) shows an overall high level of embodied primary energy in order to improve the building envelope up to such a very low heat transmission value needed for a passive house. The peaks of material input is the glulam timber, the gypsum fibre board and the 3-layer insulation glazing with an amount between 25 and 30 tons. The sawn timber spruce and larch and the OSB have 8,6 to 14 tons and therefore they are slightly above the average of the mass distribution with 8,45 tons. Looking at the PENR you can recognize the correlation between the mass and the energy demand of 3-layer insulation glazing. The glazed area is only slightly reduced at five percent compared to the old façade. Therefore the new glazing has a 50 % higher mass due to the 3-layers of glass. PERE is important for the balance because the facade retrofit uses the TES EnergyFacade, a timber framed structure with insulated cavities and a rear and front paneling of the element.

The case study Buchloe shows distinct, that improvements in building performance require higher input of resources than can be acquired from the existing construction. The evaluation of the recycling potential will be completed shortly and added to this report. The recycling balance probably will not influence the entire balance a lot, as shown in the case study GWG München.

The savings of the passive house school of primary energy in building operation amortize within five and a half years compared to the material input. School buildings will be improved very effectively not only in the building envelope. The highly efficient building services can save a lot of primary energy for ventilation with heat recovery, lighting, and a reduced heating technology. The share of the primary energy content renewable is very low compared to the non-renewable portion that has 5, 2 years payback period for its own.

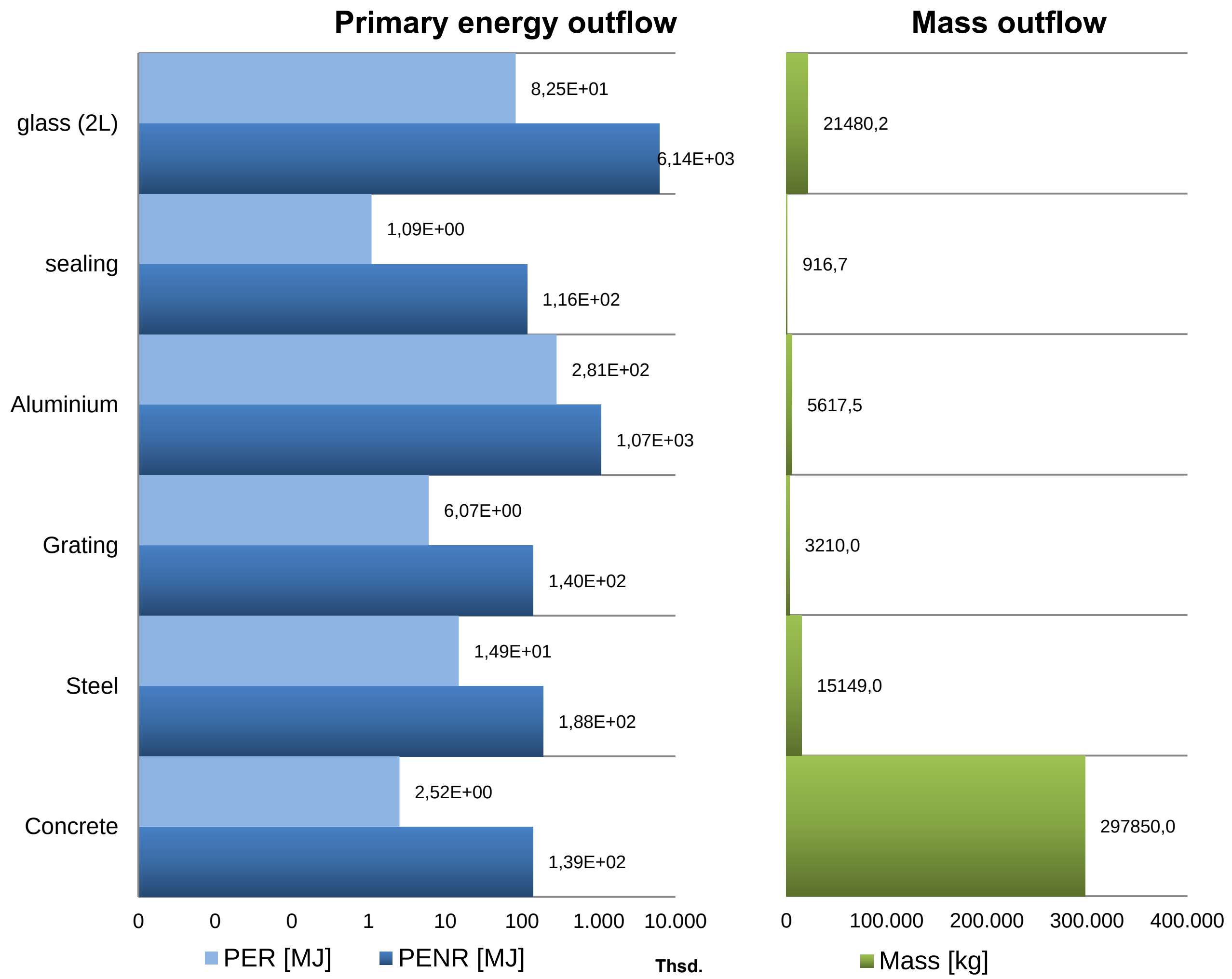


Figure 2-21 Case study Realschule Buchloe: Outflow from Dismantling (Ott)

Table 2-7 Case study Realschule Buchloe: Waste scenarios for all outflow categories (Ott)

Waste scenario	**Material**	**Mass** [kg]	**Output, PEI** [MJ]		**Recycling potential PEI** [MJ] (Ökobau 2009)	
			not renewable	renewable	not renewable	renewable
Landfill	concrete	93045,12	43382,29	787,01	14887,22	986,28
Sum		**193614,41**	**43382,29**	**787,01**	**14887,22**	**986,28**
Recycling	steel (from concrete)	15149,00	187847,60	14921,77	-177243,30	-189,36
	sheet metal	3210,00	139956,00	6066,90	-40767,00	-190,03
	aluminium	5617,48	1067321,72	281435,88	-612305,62	-208970,36
Sum		**8208,51**	**1395125,32**	**302424,55**	**-830315,92**	**-209349,75**
Possible Recyling	glazing 2-layer	21480,18	6143331,48	82483,89	k.A.	k.A.
Sum		**21480,18**	**6143331,48**	**82483,89**	**k.A.**	**k.A.**
Thermal Use	sealings	916,65	116414,55	1090,81	-5537,48	-49,77
Sum		**916,65**	**116414,55**	**1090,81**	**-5537,48**	**-49,77**
Total					**-820966,18**	**-208413,25**

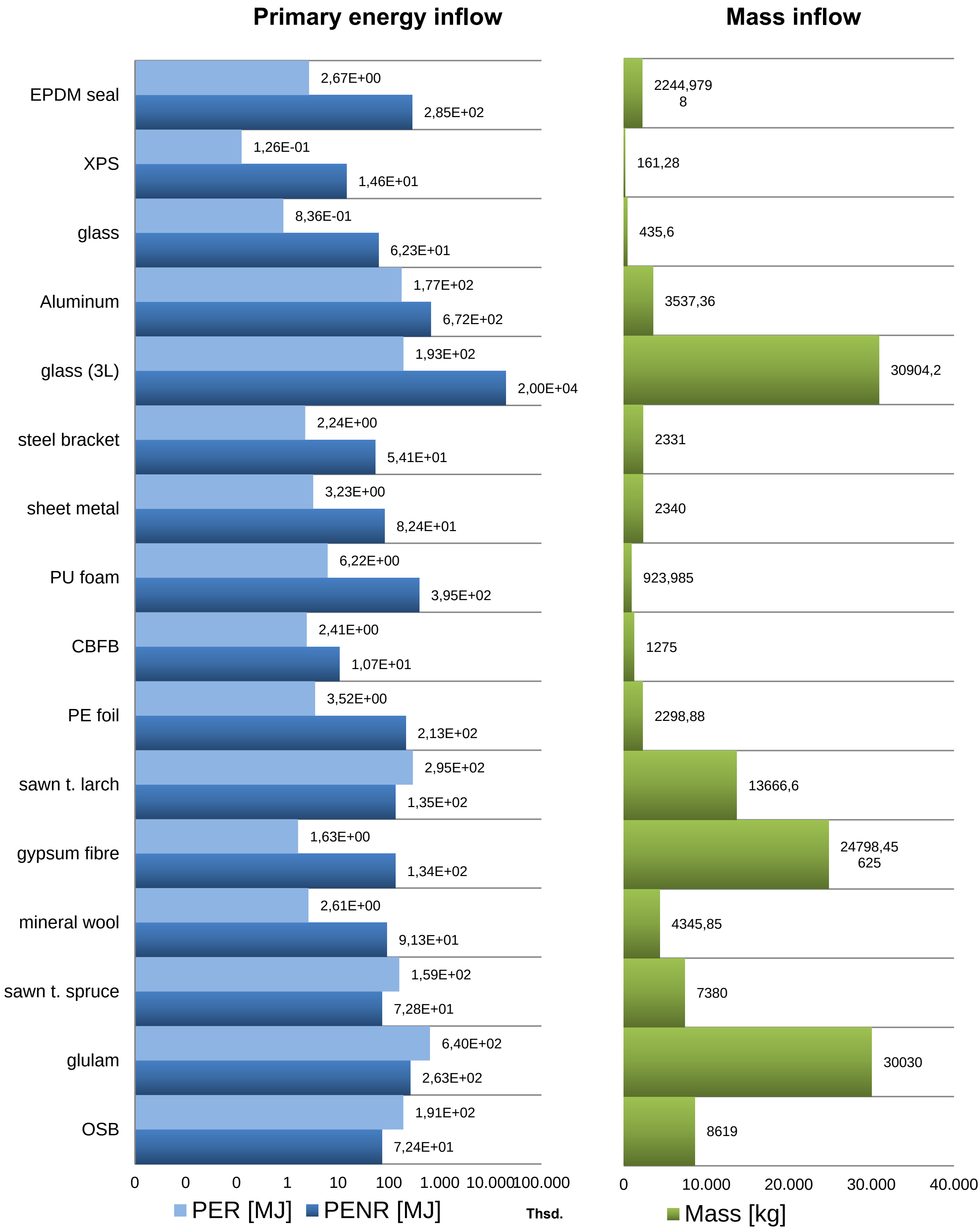


Figure 2-22 Buchloe Inflow from Refurbishment (Ott)

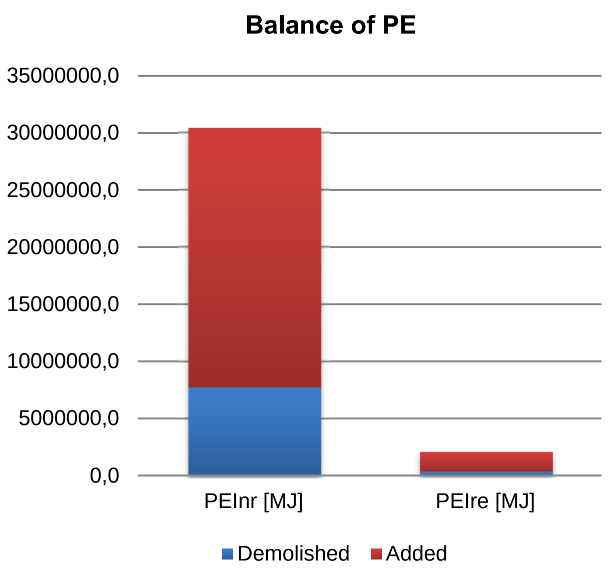
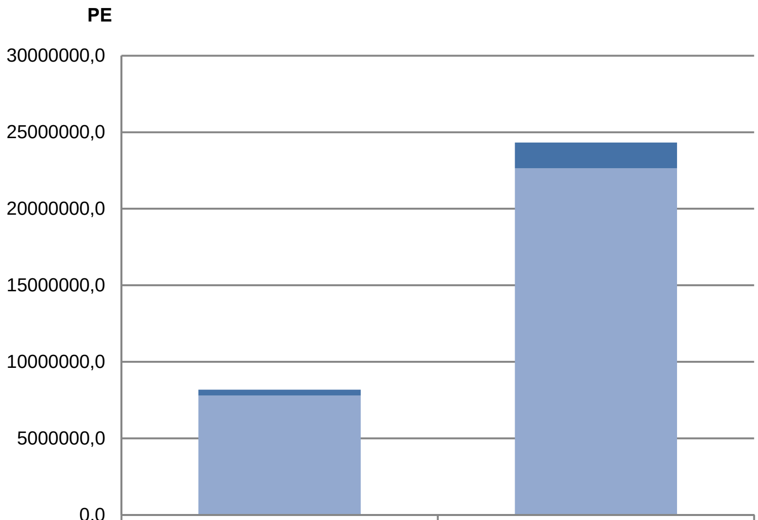


Figure 2-23 Buchloe balance of primary energy (Ott)



	Demolished	Added
PEIre [MJ]	388518,6	1682112,2
PEInr [MJ]	7793743,9	22642064,5

Figure 2-24 Buchloe balance of primary energy through all steps of retrofit, including the end-of-life for demolition (Ott)

2.5.4 **PSOAS Oulu, Virkakatu 8**

Figure 2-25 Process of change from original building, refurbishment site process, to end result at E2ReBuild demonstration project PSOAS Oulu (photos M3 Architects, le Roux)

Case study PSOAS Oulu, Virkakatu 8, in Finland is an example of a deep retrofit of an institutionally owned rental apartment housing block. [16] The building was built in 1985 and has been completely refurbished. Construction work started on site in mid-2012 and finished in early 2013, after an 8 month construction process, beginning with the demolition of the outer shell. The Oulu E2ReBuild [17] pilot is the second refurbishment in Finland realized with TES energy facades.[18] The energy efficiency target was set to Finnish VTT passive house recommendations.[19] Performance targets above and beyond regulation standards for new buildings were applied to the refurbishment, including the reskinning of the building envelope, a new ground floor slab, new building services and new apartment interiors.[20]

Outflow

During demolition four main components of the existing construction are dismantled. The outer layers of the exterior sandwich walls are demolished, which contain the brick layers and the insulation layer as well as the windows. The non-insulated and moist concrete ground floor slab is removed as well. From the main construction components finally the roof has to be replaced. Most of the non-load bearing interiors are removed due to a new layout of the floor plan and the previous mentioned demolition of the ground floor slab.

Separation of all materials from complex construction components is a high effort. All components apart from the ground floor slab contain reasonable amounts of insulation material either glass or stone wool, which is hard to separate completely. Especially the sandwich construction and the closed dry wall constructions cannot be demolished and separated properly (**Figure 2-25**). The process of stripping off the brick wall and the insulation from the concrete wall cannot be done without risk for the workers and the local environment. The demolition process and the on-site separation of sandwich components have to be planned and done properly to avoid unnecessary pollution. The remaining concrete wall has to be steam cleaned finally to remove insulation and mould. Other parts like the monolithic ground floor slab and the roof construction made of trusses and other subcomponents are much easier to tear down and separate into different material fractions. Roof and ground floor slab were two of the heaviest components during demolition which contain about 59 % of the total demolition mass (**Figure 2-26**). The heavy exterior wall had contributed about 29 % and the other components cover remaining 12 %. The sum of outflow of primary energy non-renewable is 323.493 MJ and about 63 % of the primary energy renewable with 510.008 MJ. The reason for the high amount of renewable primary energy is demolished renewable materials in the roof and windows.

End of Life

None of the demolished components is supposed to a reuse scenario similar to previous examples. Therefore the end of life scenarios as defined in ökobau.dat are applicable to recovered materials (**Figure 2-27**). The recycling potential and the resulting bonus of primary energy are high for windows and roof constructions. This is a result of thermal use of the renewable resources in these components. Further benefits in recycling potential result from steel which is brought back into the production process and reduces the amount of full processed raw ore which will save primary energy. The dry walls and the ground floor slab contain steel profiles and reinforcement bars which will be recycled as well.

Remaining components do not have considerable shares of recyclable materials; these are mineral wool insulation, mortar and bricks from masonry. Their main content goes to landfill which results in a primary energy burden without bonus.
The total amount of end of life primary energy non-renewable is -2.998 MJ a good result due to benefits from recycling. The amount of primary energy renewable is even higher with 132.949 MJ mainly based on thermal use. The total end of life balance shows a limited influence of the recycling potential on the resource consumption of the entire retrofit project.

Inflow
The disposed components must be replaced to improve energy efficiency and to restore the functionality. The new materials and components which have to be used on the retrofit of the building are more energy efficient. The construction has a higher performance through additional functional component layers and insulating material than before as it is illustrated in the balance sheet totals (**Figure 2-28**). The share of non-renewable primary energy in the newly built materials is 115% higher than the original building. In the renewable primary energy he even rises to 150% due to the additional timber framework in the TES façade. The largest single items of material and energy flow occur at the roof and exterior walls. Windows and new construction of the floor slab with insulation have a significant impact on the primary energy balance.

The environmental impact of the global warming potential of the large amount of new material rises very high with 15.580.646 kgCO2eq. One has to know that the proportion of the new floor plate is almost 99 %, or 15.580.646 kgCO2eq. You should know that the proportion of the new base plate is almost 99 %, or 15.570.432 kgCO2eq. This high amount is mitigated by the CO2 storage bonus of renewable resources of -33.010 kgCO2eq.

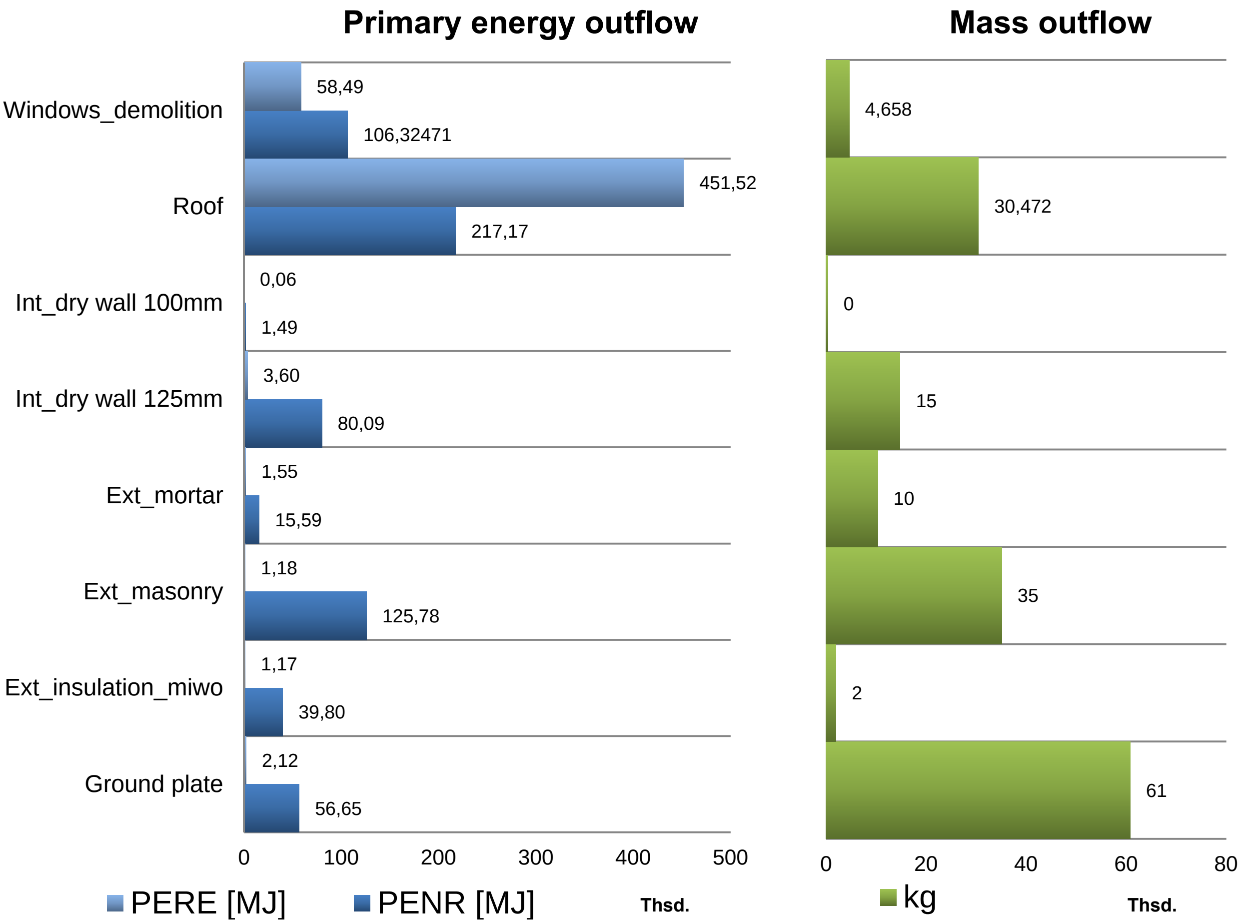


Figure 2-26 Case study PSOAS Oulu: EoL scenarios are according to Ökobau.dat 2009 (same as database for PE and GWP indicators) (Ott)

Table 2-8 Case study PSOAS Oulu: Waste scenarios for all outflow categories (Ott)

Waste scenario	**Material**	**Mass** [kg]	**Outflow** [MJ]		**Recyclingpotential** [MJ]	
			PENR	**PERE**	**PENR**	**PERE**
Landfill	Ext_insulation_miwo	1.971	39.797,55	1.169,51	315,30	20,89
	Ext_masonry	35.134	125.778,65	1.176,98	5.621,39	372,42
	Ext_mortar	10.322	15.586,82	1.548,36	1.651,58	109,42
Possible	Ground plate	60.831	56.654,67	2.118,36	-108,26	-410,70
	Int_dry wall 125mm	14.782	80.092,19	3.601,29	199,2	-8.950,10
	Int_dry wall 100mm	325	1.493,73	63,59	2,04	-96,7
	Roof	30.472	217.168,92	451.516,72	-1.784,24	-71.707,46
	Windows	4.658	106.324,71	58.491,34	-8.895,58	-52.287,44
TOTAL		**158.495**	**323.493,63**	**510.008,06**	**-2.998,57**	**-132.949,68**

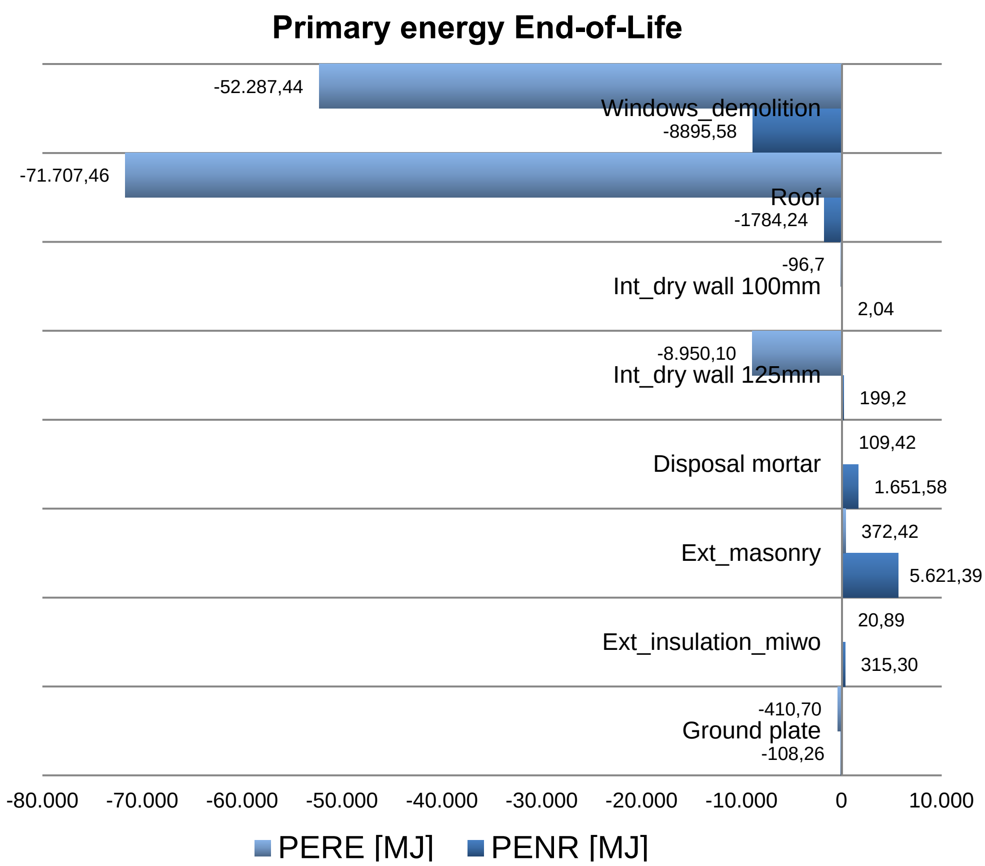


Figure 2-27 Case study PSOAS Oulu: Primary Energy content for end of life (PE): End of life balance PE from refurbishment (Ott)

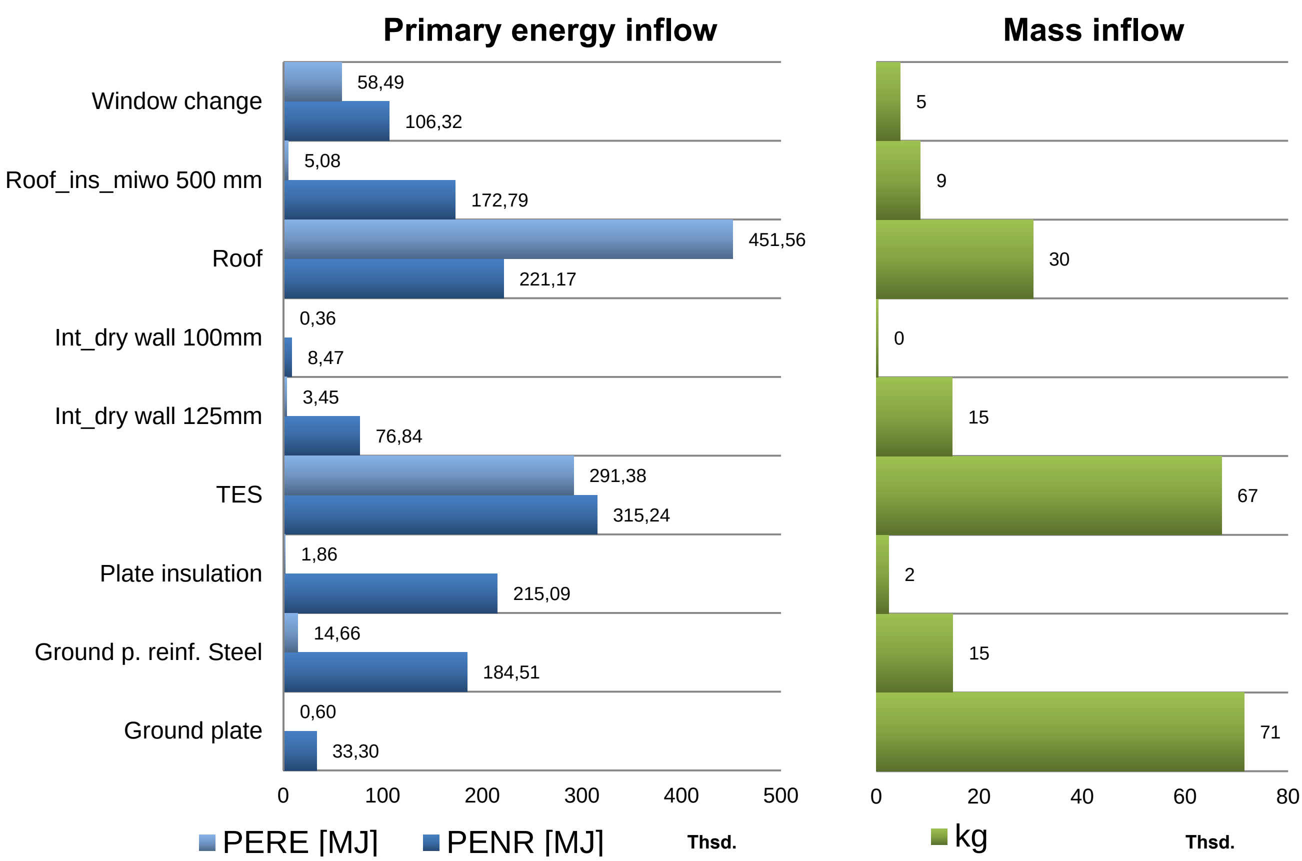


Figure 2-28 Case study PSOAS Oulu: Primary Energy content for production (PE): Inflow balance PE from refurbishment (Ott)

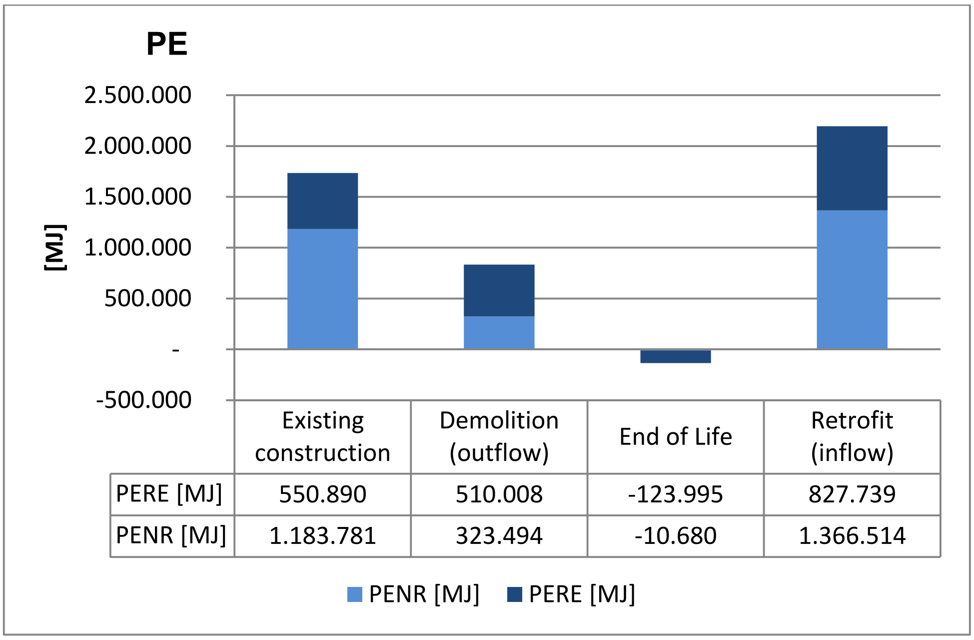


Figure 2-29 Case study PSOAS Oulu: Balance of primary energy through all steps of retrofit, including the end-of-life for demolition (Ott)

2.6 Discussion on Limitations of metrics on building level

The large effort required to completely describe the building can be reduced to a limited number of critical key performance indicators.

Energy analysis related to material flow and the dominance of the use phase has to be questioned, and more emphasis placed on immediate impacts.

The accurate determination of resource consumption provides manufacturer with specific hints for greener and more economical alignment of the product. It is noted that by mostly renewable materials there is little or no adverse environmental effects. Façade elements show inherently better deconstruction properties due to layering which protects the core substance. The reuse and cascade use of materials used is very high, because they are added in pure form and without chemical bond with each other. The ingredients are safe and non-hazardous.

2.7 Conclusions

Sustainable retrofit must analyse each construction project from a life cycle perspective. It is to include alternative retrofit methods such as SmartTES. The environmental impact can be determined at the product level by material flow analysis and LCA methods. The previously recognized potential for optimization must be transformed into future, marketable products. More detailed studies on the long-term robustness of multifunctional wooden facades are required.

The final overview on all three cases gives a similar pattern. The outflow and its embodied energy are strongly dependent on the depth of intervention. Deep retrofit with major changes in the building envelope as well as changes on the primary structure reach up to 50 % of embodied energy of the original existing substance. The End of Life of the material outflow can contribute to a reduction of embodied energy when recycling scenarios are applied. Consequently the share of this reduction is quiet low compared to the total outflow of embodied energy.

The application of TES elements adds new materials for the old, demolished materials. Among the fluxes are the energy flows for the manufacture and installation. On the input side appears high primary energy content, these are mainly bound to the material aspect of renewable resources. Which is a bonus for the end of life, because in a distant future, these bound resources can be accessed and utilized environmentally friendly. It requires a careful use of the material and embodied energy today while the future use has to remain at tolerable levels and should cause little environmental impact as possible. In particular, designers and wood contractors need to consider these potential problems in the project and product development.

It appears that renovation projects with TES produce a higher outflow of materials and will therefore release more embodied energy. This means that TES tends to require deep retrofit actions. It is more likely related to bigger effort also on the material inflow side, because every removed construction component has to be replaced by a new component in order to make a building functional working. Seldom components are redundant and can be skipped after demolition. An additional amount of embodied energy is generated and changes the environmental impact. This is just a first impression based on the available data and analysis results. For proof of this guess also conventionally retrofitted buildings have to be assessed holistic and in depth. The possible relationships between restoration methods and scope cannot be determined without detailed analysis, for this further practical examples need to be studied and evaluated.

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3. Robust product engineering

Stephan Ott
TUM Technische Universität München

3 Robust product engineering

3.1 TES technical / product level

3.1.1 Goal and scope

In the near future product costs will be mainly defined by the rising costs of shrinking resources and environmental protection; as communicated by the European Commissions on a resource efficient Europe.[1] This development needs new strategies for constructions, especially in the current resource intensive building sector. The enhancement of resource efficiency reduces material flows. This has an important influence on the carbon footprint of a TES EnergyFacade construction system in comparison to other functional equivalent systems.

The building envelope and here especially roofs, outer walls and windows contribute towards up to 45 % of the global warming potential (GWP) of a conventional building. [2]

Methods of resource efficient design of construction systems have to be applied to TES EnergyFacade already in the product phase. This will be done by methods of LCA and analysing material flows.

Therefore this chapter deals with the:

- Environmental properties on facade **product level,**
- Robust construction design for **less environmental impact,**
- Cooperation with €CO2 on wood construction system LCA according to latest **standards** by CEN/TC 350,
- LCA benchmarks for smartTES elements based on **LCA** calculations.

3.1.2 Objectives

(1) Definition of an appropriate framework for smartTES on the product level considering all variable parameters of a smartTES element
(2) Collection of transparent information for assessment procedures
(3) Development of an easy to use calculation tool for safe and fast inventories
(4) Detailed analysis of smartTES compositions and discovery of sensitive parts.

3.1.3 Methods

(1) Uses conceptualization method for definition of life cycle analysis process (functional unit, boundaries, etc.) and data selection which is based on actual standards and findings from the Woodwisdom-Net research project €CO2.
Methodology for (2) is by terms of a life cycle inventories LCI (physical mass allocation of the input and output flows for basic ecologic measures in the smartTES system itself)
(3) Practical impact analysis LCIA is implemented in a software tool and appropriate data is designated.
Issue (4) uses dominance analysis to determine the relative importance of each variable as method as well as benchmarking the environmental impact of smartTES.

3.1.4 Introduction to robust product engineering

Sustainably built and modernized buildings must be economically, socially and ecologically sustainable. In addition to organizational and technical aspects, as well as the optimization of the planning and construction process, fire protection, or the hygrothermal building physics, is therefore the life cycle-oriented consideration of ecologic quality of vital importance for the development of new modernization solutions [3]. The ageing building stock in Germany and most of Europe is in a change phase. An amount of around 45% of the existing buildings from the age class of 1950 to the eighties of the last century is facing a need for major renovation that goes beyond ordinary maintenance and repair. The building performance neither fulfils the actual technical and functional requirements nor the demand of owners and tenants.

Currently, the usual answer to this need for renewal is the application of external thermal insulation compound systems made of mineral fibre or for economic reasons polystyrene hard foam. The installation of these systems is awkward work and labour intensive, subject on the weather, becomes more difficult with increasing insulation thickness. These market dominating insulation systems are manufactured from non-renewable raw materials and are energy-intensive in the production and assembly. In polystyrene rigid foam there are risks in terms of the environment and human health, especially by the contained flame retardant which can find different pathways into the environment.

Energetic counteractive measures must be carefully considered out of social, environmental and process planning considerations and compare different solutions; it must ensure a balance between the environmental impact of the manufacturing phase and the reduction of environmental impacts during building operation. Even if energy efficiency related refurbishment mainly targets a reduction of greenhouse gas emissions in building operations, so too the LCA of a reorganization measure itself, i.e. the primary energy use or greenhouse potential in production, as well as possible risks and hazardous material loads should be considered during production, processing, use and end of life.

Hence it remains a contradiction between improving the environmental performance of existing buildings and the use of fossil based resources to achieve this goal. In order to realize a better energy efficiency of the building stock there is a need to (1) bring down buildings energy demand by changing the heating system and source, (2) improving the building envelope (windows, wall, windows, ground floor, roof) and in addition (3) minimize the impact from refurbishment by retaining useful materials from the existing fabric, prolong buildings' service life, choose durable and multifunctional (flexible solutions) by the use of an off-site process before facade elements are assembled and wrapped around the existing fabric.

The goal of product level TES sustainability work is the preparation of basic environmental system declarations and the recording of the environmental properties of the prefabricated smartTES Facade retrofit product. smartTES is synonymous with Timber-based Element System for the energy efficient refurbishment. It is the fundamental step towards the description of the environmental quality of a smart envelope refurbishment method. The task is a comparison of various dependencies between the technical requirements and the material outcome, which is relevant for the environmental characteristics of the smartTES system. The main objectives for a practical application of reduced environmental impact are defined by König et al.[4] The impact for the most influential life cycle phases – production and end-of-life – has to be quantified for sustainability benchmarks. This information is required in certification systems and supports decision making.

SmartTES facade elements consist of a timber-framework construction with highly insulated cavities. The prefabricated framework is produced off-site and assembled on-site with an adaption layer onto existing structures or exterior walls. The cladding material and windows can be freely chosen as liked. These will be mounted onto the elements that should be done off-site as well. Due to the high level of prefabrication, the facade's on-site assembly process is short and causes minimal production of waste.

The major parts of the system do not have the highest environmental impacts, because they are from renewable resources. Rather, it will be revealed that these parts make a positive contribution to the environmental impact by sequestering a high percentage of carbon. This property is very similar in various construction structures, as the dominant materials are composed from renewable resources. The disposal of such materials can take life cycle credits from the energy generation from wood to a substantial extent. The environmental burdens are mainly on the account of the mineral-based components on the system.

3.2 Environmental System and Product Declarations (ESD and EPD)

3.2.1 Political goals and directives

Besides the energy efficiency of buildings the issue of construction activities and the related material and energy flows is part of the political agenda in Europe. Improving resource efficiency and reducing environmental impact of the construction sector to reduce its high consumption of raw material is seen as high potential in the next decade.

Facing limits of economic growth and the environmental risks from construction there are political initiatives on the European level. The Resource Efficiency Flagship Initiative is under the Europe 2020 strategy on the political level. Overall aim of the initiative is to handle needed materials and resource stocks most efficient to boost a green technology sector. The commission stated for the construction sector that it "will develop harmonised rules on the declaration of the performance characteristics of construction products in relation to a sustainable use of natural resources in the context of the Construction Products Regulation".

For the construction sector the new Construction Products Regulation (EU) 305/2011, which has come in force in July 2013, acts for the construction business on the construction resources. A new substantial article aims at protection of ecological assets therefore it requires environmental impact information like lifecycle impact declarations (EPDs), statistics, facts (CEN standards) of buildings and building products, also following the Commission's chemicals directive (REACH), and several other environmental goals that support overall sustainable development.

Why perform LCA studies and why is smartTES assessed in an enhanced screening study? A screening LCA study may serve for an initial (quick) overview of the environmental impacts of smartTES is helpful, but is does not communicate all the issues of a full assessment. The challenge with screening methodology is to adapt the LCA methodology and simplify the use of LCA.

Screening studies cannot retrieve detailed results, due to the fact that it cannot bring all data from a real process or a real life cycle. The nature of a screening study is a focus on the main contributors to SmartTES system. Only a limited number of indicators are used for the description of the functional unit. The procedure of the screening, the functional unit and the assessment results will be shown in the following section in this report

3.2.2 Standardization on product level

CEN/TC 350 plays a leading role at the level of sustainability standardization in the construction industry. It writes the standards for the overall European frameworks and provides core rules for building LCA and product level category rules. This specific product level is regulated in addition to the building level. This level directly affects the smartTES elements as products for application in a building.

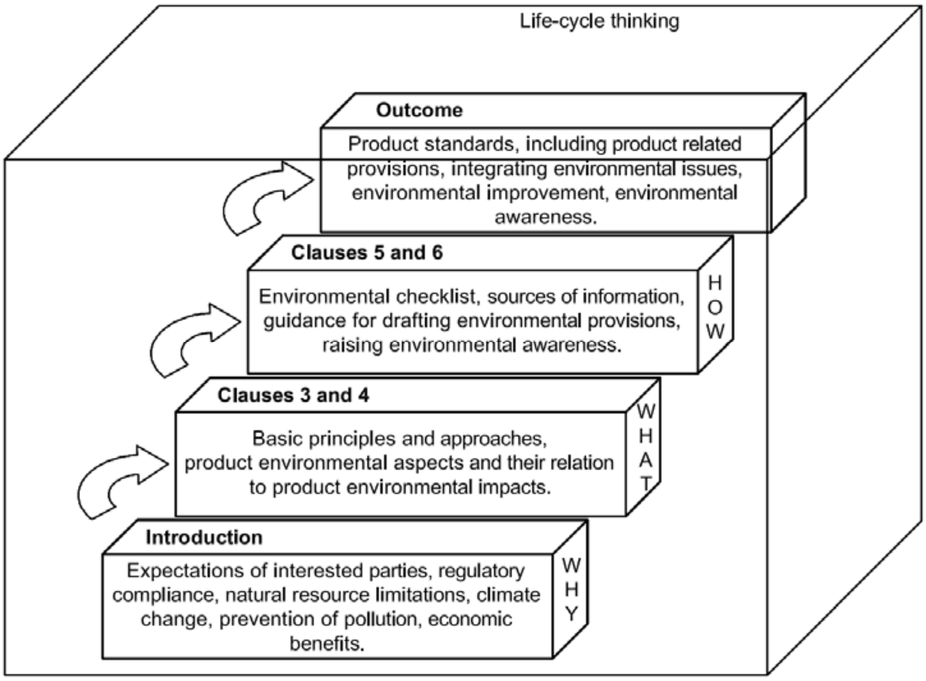


Figure 3-1 Product development contains a sequence of steps to achieve life cycle thinking. [5]

The CEN Guide 4 is generic, not dedicated to one single group or product, and is similar to the ISO 14040/14044 standard series.[6] It provides guidance in developing product standards and is intended to strengthen the life cycle thinking in product standards, and encourages the understanding of environmental aspects and impacts on the product level. This is done in specific steps during the development of standards (**Figure 3-1**). The first step is to identify the product environmental aspects and their relation to environmental impacts. The next step is to identify the interdependencies of these environmental aspects with the product. This is done by checking the product environmental information. These parameters have to be checked throughout all life cycle stages.

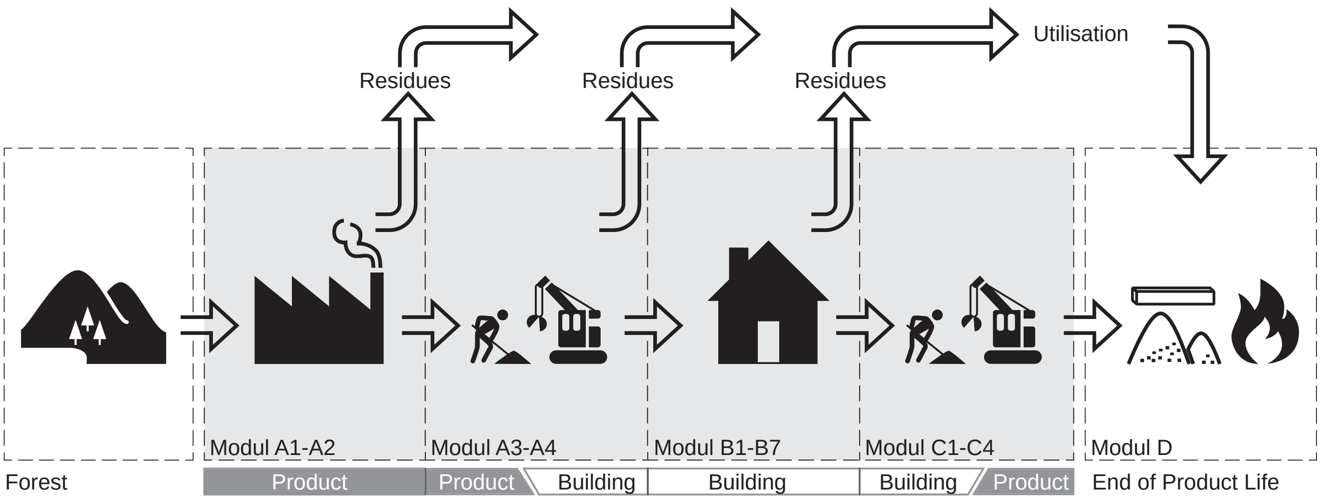


Figure 3-2 Product life cycle and system borders along the life cycle (Ott)

Discourse on the life cycle dilemma

In the construction sector life cycle is an ambivalent issue. On one hand the use of resources during long building life spans is positive. On the other hand the life cycle is not always linear and gets complex due to building's extended product life especially when it comes to retrofit actions within the whole life cycle. SmartTES faces this question on the building level. The building level was already discussed in section 1 (smartTES work task 5.2).

In addition there is the product level. Here the complexity lies in the field of material flows, cut off and system borders as well as residues, side products and correct allocation together with a problem of inappropriate data and making assumptions. The product level is mainly the work of this section (smartTES task 5.3).

The life cycle of a building is separated into four separate modules, which start with the production phase "A", followed by the use and operation phase "B". The penultimate module is the disposal phase "C", and the benefits and burdens of the remaining materials are summed up in the final module "D", which is normally the end of life. The order of the modules does not change. The duration of each module is variable, as is the entire product life. Most relevant is module B since it can endure for long time. Each phase in a certain module requires specific data and has a different flow of materials (**Table 3-1**)

Table 3-1 Generic life cycle modules according to EN15804 and information available for calculating smartTES EPD (Ott)

	Phases	*Data*
Module A	**A1-A3 (cradle to gate)**	**YES**
	A4-A5 (gate to site)	Generic assumptions for prefabrication
Module B	B1-B5 (use and operation)	NO (missing data) – Use, Maintenance & Repair
	B6 (energy)	NO – Energy (energy simulation for building)
	B7 (water)	NO – Water (calculation rules)
Module C	**C1-C4 (end of life)**	**YES** partly (only C3-C4) - End of Life
Module D	D	NO (missing data) – Credits and burdens

Environmental information for practical application has to be made available in environmental product declarations (EPD). An EPD communicates verifiable, accurate, non-misleading environmental information for products and their applications, thereby supporting scientifically based, fair choices and stimulating the potential for market driven continuous environmental improvement. For smartTES there is a variety of materials used and composed to a new product system. Most of the used materials have environmental product information available. These will be used to make a new summary of information about any specifically composed SmartTES product system and its impact on the environment.

While informing about a product or a product system two sides have to be considered, the input side and the output side. On the input side there is the amount of materials used, expressed in primary energy content of each material and separated in the primary energy non-renewable and primary energy renewable. The non-renewable resources are non-renewable raw materials and non-renewable energy (e.g. coal, fossil oil or fossil gas) used for production of the product. Renewable resources are raw materials based on biomass and renewable energy from sources like wind, photovoltaic, biomass or hydropower. Taken into account is also the water consumption, secondary material and secondary fuels.

Waste is also separated into different categories as hazardous waste, non-hazardous waste and radioactive waste. The information on the output side is many categories but in the construction sector only few are seen as relevant today. There is ozone depletion, acidification, eutrophication, photochemical oxidants, and abiotic resource depletion. The most important category at the moment is GHG emission of products and buildings in use. Information from this category is relevant in relation to the global warming problematic and the European goals of GHG emission reduction in order to mitigate climate change.

For the wood sector this information is also very important; as wood is a renewable resource which absorbs a lot of carbon from atmospheric CO2 during growth. To give appropriate figures of such benefit for the global environment there was a Woodwisdom-Net ERA-Net research project called **€CO2** from 2010 to 2013.[7] €CO2 looks closely on the balancing of carbon emissions and carbon storage in life cycle wooden buildings. Procedures were defined for the life cycle assessment of wooden buildings according to the overall framework of EN 15978. The carbon stored in wood as material is calculated according the rules of prEN 16449.[8] In the total balance a carbon footprint of a wooden building or a wood based product causes less environmental impact on the global climate and mitigates climate change more effectively than other products.

The product level has to provide the necessary information for building LCA and carbon foot printing. Here is all information collected about a certain product or product system and its environmental aspects, according the standardised procedures of EN15804 and provided for building LCA. While the standard EN15804 provides only core product category rules, the prEN16485 defines the specific product category rules for EPDs of basic wooden materials.[9] Similar specific PCR are developed for various products, not only wood-based products.

3.2.3 **LCA procedures**

Building Life Cycle Assessment

The creation of a building life cycle assessment (LCA) is an important part of the sustainability analysis. Here, the building throughout its entire life cycle is considered from the building erection, operation and the final disposal. Data from the LCA of used building materials, or of the created components must be at hand for the determination of the environmental effects of a building with regard to construction, waste disposal, as well as eventual replacements of components within the period under consideration. For better understanding of the following observations of the LCA of SmartTES elements the method of LCA and the terms associated are explained in advance.

Methodology of Life Cycle Assessment

The method of life cycle assessment is used to assess the environmental impacts of a product. It considers the entire life-cycle from raw material extraction to disposal. The principles, conditions, requirements, and instructions for creating life cycle assessments of products are internationally standardized in EN ISO 14040 and DIN EN ISO 14044.[10] [11]

A life cycle assessment is therefore divided into four parts: goal definition, inventory analysis, impact assessment, and evaluation. The definition of the target provides the framework of investigation and must ensure comparability with similar products through the definition of the functional unit. This meant that not to capture only the materials used but also to be comprehensive in description of functional properties.

A product is shown as accurate as possible in terms of the materials, energy flows and other flows in the life cycle inventory (LCI). This means the input streams are recorded. Also the output streams apart from the main product, like emissions and process residues and by-products, are recorded. Unified input stream indicators capture resource and waste of material flows and are measured in the units of primary energy or water consumption, for example. To cope with this complex task, it is necessary to define system boundaries and cutting criteria.

The LCA procedure of LCI is related to primary energy use and states the consumption of energy resources of buildings in operation as well as in production of construction materials. A clear system border must be drawn between the building and the construction material. The degree of detail, as well as the various conditions for the collection of data must be distinguished. As a building usually meets a higher function than a solitary material it is aggregated from various materials. In addition, it has a procedural character, which means it can be considered not only static but consumes resources dynamically for specific life cycle stages. The consumption of energy, which was considered previously isolated, is included in the integrated accounting.

The LCA procedure of life cycle impact assessment (LCIA) works out the assumption on the environmental impact of the energy and material balance from prevailing LCI phase. The impact assessment deals with the environmental impact of the material flows and quantified these in the form of impact indicators. In construction sector, it has agreed for assessments on the following impact indicators: eutrophication potential (EP) in phosphate equivalent, ozone-depletion potential (ODP) in R11 equivalent, photochemical oxidation creation potential (POCP) in ethylene equivalent, global warming potential (GWP) in CO2-equivalent and acidification potential (AP) in SO2 equivalent.

LCA data and databases

The data need the information for the calculation of life cycle assessments to thing and the associated work indicators. They are collected in databases, in which basic raw materials and processes are stored, is an example of ecoinvent.[12] There are special thing databases such as the Ökobau.dat that contain only data for the construction industry.[13] With the Ökobau.dat inventory and impact indicators of typical construction products are available, which material comes from various raw material sources and is produced in different processes. This one has aggregated industry-wide average data of the respective materials. Now more and more product-specific data recorded by certain producers in the ökobau.dat, which creates a certain inconsistency between aggregated and specific data. How further development looks like is impossible to judge.

Environmental Product Declarations

The results of the life cycle assessment of construction products are among others in vendor-specific environmental product declarations (EPD), used for the application in the field of sustainable construction. For environmental product declarations is type III environmental labeling according to ISO 14025.[14]

Typical characteristic of these environmental labels is a systematic and comprehensive description of the environmental performance of the product without classification.[15] The complementary standard to DIN EN ISO 14025 for the construction sector is the ISO 21930; it regulates the principles and requirements for type III declarations of building products using basic product category rules (PCR). This means the products are balanced according to standard rules of product groups and the results are checked and released by an independent body:

"An important development step in the framework of the European harmonization process for building products the introduction of the new building products directive in addition the new basic requirement no. 7 "Sustainable use of natural resources" was recorded. For this basic requirement, as well as the basic request no. 3 "Hygiene, health and environment" an EN 15804 conform EPD can directly be used for evidence." [16]

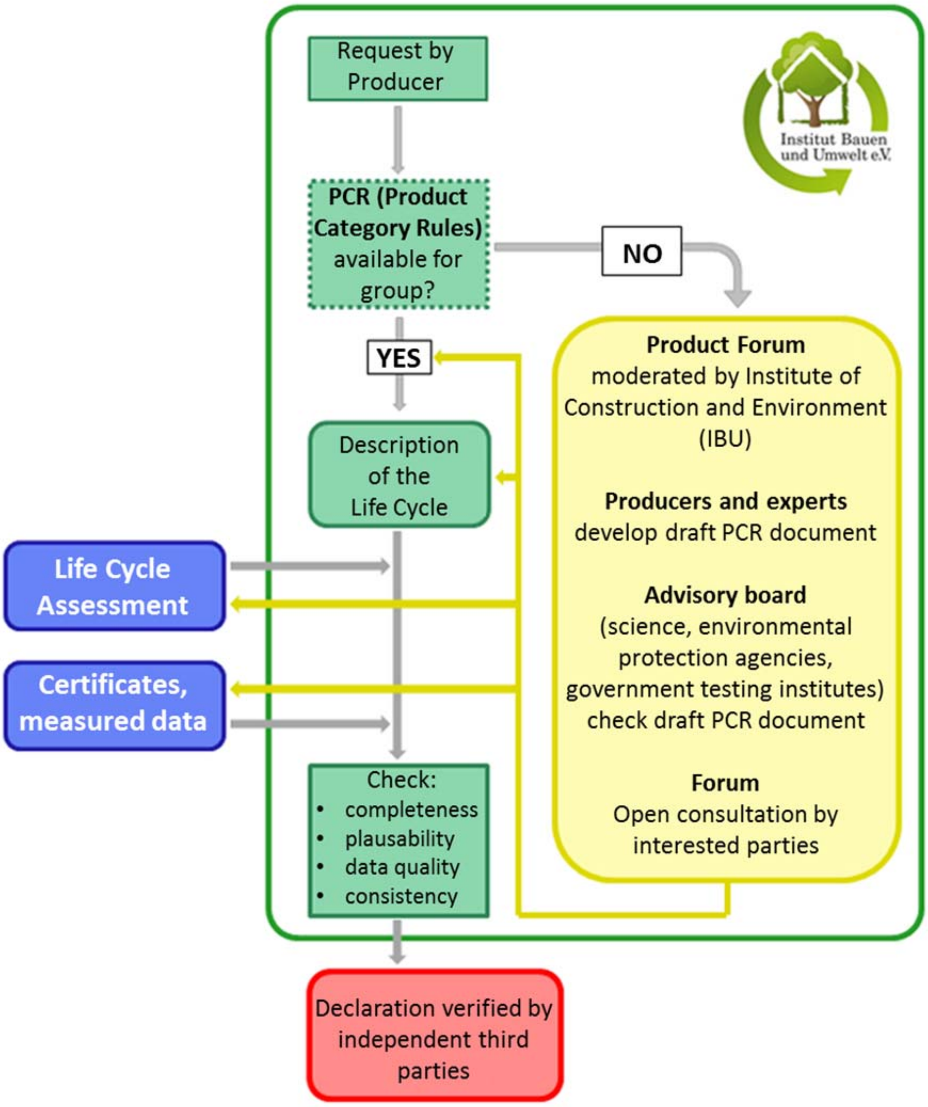


Figure 3-3 Formal procedure for development of EPD, according to German IBU [17].

Environmental system declaration
SmartTES has a complex and prefabricated structure and is therefore more difficult to cover with a normal product declaration for semi-finished products. It is a mixture of materials and a possibly upstream manufacturing process. This is comparable to other construction components like windows. For such higher level products environmental system description (ESD) are used, which can be explained as a formulation for a whole set of low-level EPD.

There is a generic description as a framework that provides the definition of functions and possible materials. The composition of varying materials and functional properties make different, specific products out of a generic smartTES formulation. Each of these has its own ESD only valid for the specific formulation of layers.

Even various materials can be used for a specific layer in the SmartTES component. A manufacturer, who would like to produce an ESD for his specific SmartTES product, must abide by the functional description and can then combine his preferred materials in conformity with the generic ESD code. Hence he has an ESD for a specified product with own indicators for environmental impact.

List of the most common used indicators of construction sector:

a) **Primary energy content**
The primary energy demand can be covered by different types of energy sources. The primary energy demand is the quantum of energy taken directly from the atmosphere, hydrosphere and geosphere or energy sources that was not subjected to any anthropogenic transformation. Fossil fuels and uranium, this is expressed in energy equivalent (energy content of energy raw materials) such as the amount of removed resource. For renewable sources of energy, the energetically characterized amount of biomass is described. Hydroelectric power is the amount of energy of water obtained from the change in the potential energy (from the difference in altitude). Following primary energies are reported as aggregated values: the checksum value of "Consumption of primary energy is not renewable" expressed in MJ characterized primarily use of the energy of natural gas, oil, lignite, coal and uranium. Natural gas and oil are both used as material e. g. for plastics. Coal instead is used mainly for electricity production. Uranium is only used for electrical energy generation in nuclear power plants.
The total value of "Renewable primary energy consumption" specified in MJ is usually shown separately and includes wind, hydropower, solar energy and biomass. It is important in any case that used final energy (E.g. 1 kWh of electricity) and used primary energy not resolves, because otherwise the efficiency of production or provision of final energy is not considered. The energy content of manufactured products is shown as fabric-bound energy content. He characterizes the lower calorific value of the product. It represents the still usable energy content.

b) **Global Warming Potential**
The mechanism of action of the greenhouse effect can be observed on a smaller scale, as the name implies, in greenhouses. This effect takes place also on a global scale. Incoming short-wave solar radiation striking the Earth's surface is there partially absorbed (which leads to a direct heating) and partly reflected infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and directional again emitted so that it will be partially transmitted back to Earth. This leads to a further warming.

c) **Ozone Depletion Potential**
At high altitudes, ozone is formed by the irradiation of oxygen molecules with short UV light. This leads to the formation of the so-called ozone layer in the stratosphere (15-50 km height).

d) **Acidification Potential**
Acidification of soils and waters is mostly through the conversion of air pollutants in acids. This results in a reduction of the pH of rain and fog from 5,6 to 4 and below.

e) **Eutrophication Potential**
Eutrophication is an accumulation of nutrients in a location. One differentiates between aquatic and terrestrial nutrient input. Contributions to eutrophication come from air pollutants, waste water and the use of fertilizers in agriculture.

f) **Photochemical Ozone Creation Potential**
In contrast to the protection function in the stratosphere, ground-level ozone as harmful trace gas is to classify. Photochemical ozone formation in the troposphere, known as summer smog, is suspected to damage materials and vegetation. Higher concentrations of ozone are toxic to humans. Aggressive reaction products, where the main reaction product is ozone under the influence of solar radiation, result from nitrogen oxide and hydrocarbon emissions under complex chemical reactions. Nitrous oxide alone causes high ozone concentrations.

Material flow life cycle indicators
Material flow indicators are divided into Renewable and Non-Renewable Primary Energy sources (PER and PENR). A more detailed subdivision is not possible here according to the conventions of the EN 15804, because neither the used nor currently available data from the ökobau.dat conform to this standard.[18][19] The growing amount of EPD now available for various construction materials on the basis of EN 15804 shows values of the specific product. Product information is resorted also to specific EPD for the database because there are no suitable generic records in the ökobau.dat. The choice of the impact categories consists of accepted indicators in certification processes. Hence refurbishment will reduce the greenhouse gas emissions, is therefore an important reference value on the material side of the global warming potential (GWP). In addition the carbon sequestration (Cseq) of renewable materials is shown on the basis of the standard TC 175WI.[20] This advantage is evoked already in the global warming potential calculations for cradle to gate. But thermally recycled wood loses this advantage and gets CO2-neutral on the only material side at the end of the entire life cycle. Because the advantage of a CO2 absorption in wood in structure is an essential climate protection contribution, it is included informative in this investigation as a positive environmental impact.

Functional unit and System boundaries
The functional unit defines the way in which the identified functions or performance characteristics of the product are quantified. The primary purpose of the functional unit is to provide a reference by which material flows (input and output data) of construction product's LCA results and any other information are normalized to produce data expressed on a common basis.

The functional unit, used as the denominator provides the basis for the addition of material flows and environmental impacts for any of the life cycle stages and their modules for the construction product or construction service.

The functional unit of a construction product is based on: the quantified, relevant functional use or performance characteristics of the construction product when integrated into a building, taking into account the functional equivalent of the building.

smartTES functional unit
The functional unit for the product level analysis of smartTES is one square meter of core facade element with all layers of the timber framed element but without existing wall, cladding and other integrated components like windows and doors. Up to now the inflow side does not include an analysis into the accompanying parameters, anchoring, tie-back, and gap layer. The core element inventory does also not contain secondary materials i.e. tapes, nails, screws etc.

System boundaries include the production with raw material extraction, transport, and processing into semi-finished, so called "intermediate" products. The system covers all activities from the "cradle" (i.e., the extraction of raw materials, agricultural activities and forestry) up to the factory gate; this is the cradle to gate assessment according to EN 15804.[21] The off-site production of the delivered TES elements is a second factory process, but it is attributable to the construction process and related to phase A5. The transport and assembly flows in A4 are cut off from the "second" factory gate. There is still no data available for life cycle module A4-5 energy and material flows for mounting smartTES on existing buildings. The subsequent life cycle modules B, C and D are not examined here.

TES elements consist to a large extend of semi-finished products for which already environmental product declarations (EPD) are available. There are so far no detailed data recorded of energy consumption and local material flows in the manufacture of smartTES elements. Therefore comparative figures from the off-site production of timber frame construction elements will be used, similar to new building off-site processes.[22] [23]

The functional unit description will be the formulation of a generic ESD. Simple construction material have a functional unit in a straightforward matter that is related to the most common application of the material, like one cubic meter of in situ concrete or one square meter of a certain flooring material. The functional unit for the prefabricated facade elements is one square meter of facade.

The following describes the functions to be fulfilled by the components. Technical properties of the overall component consist of the separate functions of several layers and components. It is not the individual materials defined but the functions to be fulfilled. Therefore remain possibilities to optimize the design for sustainability criteria to anticipate the same function as other components. Ultimately, a functional unit can be defined only after knowledge of all materials.

It was mentioned in the ESD section above that TES elements are more complex. The functional unit for SmartTES is set in the form of a matrix, in which the different functional layers, material groups are put together. They are composed from a variety of materials with different functions within one product. The functional unit contains the generic rules how different layers are put together and what properties apply to the entire facade insulation system, e.g. a certain U-value or fire resistance class. Furthermore it defines the final metrics for a complete smartTES to make it comparable on the product level.

The material data are compiled on the basis of existing EPDs. They are also part of the LCA tool for smartTES elements. For better handling complexity the TUM has developed this LCA tool for SmartTES facade. In the LCA tool, the different combinations of materials can be selected from a database and the overall environmental impact of the functional unit of a square meter opaque smartTES facade will be calculated.

The following list can serve as a "Roadmap" for orientation in the definition of the functional unit in the individual modernisation project.

---

a. **adaption layer**: is used to compensate for any unevenness between the rough existing wall and the plan prefabricated timber frame elements. The cavity must be filled with insulation material to compensate for unevenness and to avoid uncontrolled convection.
b. **heat protection**: the prefabricated SmartTES core element is a self-supporting timber frame work and consists of studs, insulation, as well as the inner and outer panelling.
c. **weather protection**: for weather protection, there are a variety of ways. ETIC systems can be as well used as ventilated facades made of wooden boards, wood shingles, or wood-based panels. In the building classes 4 and 5 the facade surfaces must be difficult combustible. To insert normal combustible building materials, compensation measures must be taken as horizontal fire stops made of sheet steel.
d. **load transfer**: during the use phase vertical loads from dead load bear on SmartTES elements and horizontal loads from wind pressure and wind suction. Therefore elements are self-supporting. Static and dynamic stresses are added during manufacture, transport and installation. Substructures of coupling beams distribute the horizontal loads and compensate the unevenness of the existing wall for plane mounting surface.
e. **sealing**: the required air and wind seal, as well as the required fire safety encapsulation of facade elements in building classes 4 and 5 has to be consistently implemented especially for joints. Consider the horizontal and vertical element joint, as well as the tightening of base and eaves.
f. **building services integration** remains optional and is only valid for specific elements.

Life span of products *(directly related to system boundaries!)*
Service life has a huge impact on environmental information of any product, because when a product has to be changed during the estimated service life. The standard mentions the estimated service life (ESL) of a product, which is his announced duration of service life in accordance with technical requirements. The reference service life is the assumed life span of a product to do a LCA on basis of a functional unit.

Service life concepts, prediction and planning in the ISO 15686 standard series:

- ISO 15686-1, Buildings and constructed assets — Service life planning — Part 1: General principles
- ISO 15686-2, Buildings and constructed assets — Service life planning — Part 2: Service life prediction procedures
- ISO 15686-7, Buildings and constructed assets — Service life planning — Part 7: Performance evaluation for feedback of service life data from practice
- ISO 15686-8:2008, Buildings and constructed assets — Service-life planning — Part 8: Reference service life and service-life estimation

The service life of SmartTES can be planned up to now on the basis of experience from timber framed walls in new building. Furthermore the effort for exterior wall insulation with SmartTES has to be controlled and checked.

Assumptions
Data for wood-fibre insulation material is selected on an EPD basis.[24] For the wood-fibre insulation material and other wood-based materials, the carbon sequestration is estimated on the basis of the density and the usual humidity. The mass calculation receives a flat-rate reduction of ten percent, either due to the manufacturer's use of unspecified base materials. This is necessary to cope with different density of wood species and wood moisture as well as the necessary glue included in the final product

3.2.4 Life cycle benchmarks of other retrofit methods

SmartTES solutions environmental information's have to be compared to conventional other systems for building envelope retrofit. Benchmarking as a process is necessary to compare properties of the own product with other products on the market in order to improve the own quality.

ETICS comparison
The smartTES facade system serves the energetic retrofit of the building envelope in the stock. There are similar products on the market, but all of which are not prefabricated. Perhaps the most common and easiest to use system is an ETICS. Like the smartTES, it is attached to the existing facade from the outside and it is self-supporting. The ETICs has several layers with different functions such as also the smartTES. The main layer is thermal insulation. It has only a facade clothing option from a render system, which is applied as the last operation as a protective and visual surface. ETICS differs in its other properties strongly from SmartTES, it is very easy and requires no special structures to anchor, the bonding on the existing facade and a point wise anchoring with the underground are sufficient. While proper comparison needs a similar target of a product, also functional unit and technical properties should be comparable. Here the main technical property as a product is the equivalent U-value of both solutions. When different systems are comparing the goal in this report is to do it on the same U-value level.

The benchmark of ETICS is made according to the environmental system declaration (EPD) of the industry. It is therefore an aggregated ESD of German ETICS association and indicates PENR 331.18 [MJ/m²], PER 7.07 [MJ/m²], and GWP +14.48 [kgCO2eq/m²].[25] The basic ETIC system EPD uses expanded polystyrene insulation material and is therefore prevailing fossil energy and causes greenhouse gas emissions.

Module A4-5 construction specialties of ETICS
Facade retrofit systems with a high amount of work on-site work will lead to higher environmental impacts in module A4-A5, see Takano.[26] Reasons are higher efforts for transport, intensive use of construction equipment, etc. Reasoning is based on a comparison of construction works of an off-site produced wooden building with one which is constructed on-site with pre-cut but not prefabricated parts.

Module C end of life specialties of ETICS
The waste management of retrofit production is more complicated to mitigate with on-site systems. On-site production leads to a certain amount of uncontrolled waste portions. The site waste streams dedicated to recycling are smaller and more harmful, due to wetting, dirtying or contaminating of waste substances. Other streams for landfill or thermal use increase instead of decrease.

3.3 Evaluation of the smartTES facade system parts and components

3.3.1 Robust smartTES system design

Life-cycle optimized construction systems have four important basic requirements:
1) maximize the lifespan of important components such as the primary structure,
2) minimizing the flow of material,
3) increase the possibility to reuse and recycling, as well as
4) maximize the decommissioning.

The necessary and variable components of the system are described as input variable. In a poly-hierarchical model, they are networked with the requirements and further the critical dependencies with the impact on the choice of material are derived.

The four basic requirements and the objectives of sustainable product SmartTES define main objectives of the material selection, construction design and production processes for the system parts and components.

For life span of materials and products only qualitative empirical values can be derived from existing examinations. In Germany for example, the repair cycles of buildings and components are compiled and agreed on a national basis. These cycles are valid and prescribed for DGNB / BNB certification in the German guideline for sustainable buildings.[27]

For the composition of elements, that so far no composite materials are provided in rule-compliant structures. Exceptions are the sill and the sealing of the window frame. The connectors between different parts and the element with the existing construction are not fully deconstructable. For wood, limited reuse is therefore to be expected, since impurities remain on the wood in combination with nails and staples that cannot be removed.

In a multi-hierarchical model (**Table 3-2**) the product parameters are influenced by the objectives for more environmental sound elements and the available methods to achieve these objectives.[28]

Situations which exhibit characteristics of multiple categories are defined in one model of system design. This polyhierarchical model contains multiple parameters which are interrelated with environmental requirements derived from robust design objectives - in a specific sequence, for example:

- Construction design decision leads to
- differentiation of life span and
- influences dismantling behaviour.

In an analysis of the robust engineering framework (**Table 3-2**), specific methods to improve environmental characteristics are assigned to parameters appropriate for TES, and possible influences are identified in the respective results derived from the original objectives for robust engineering.

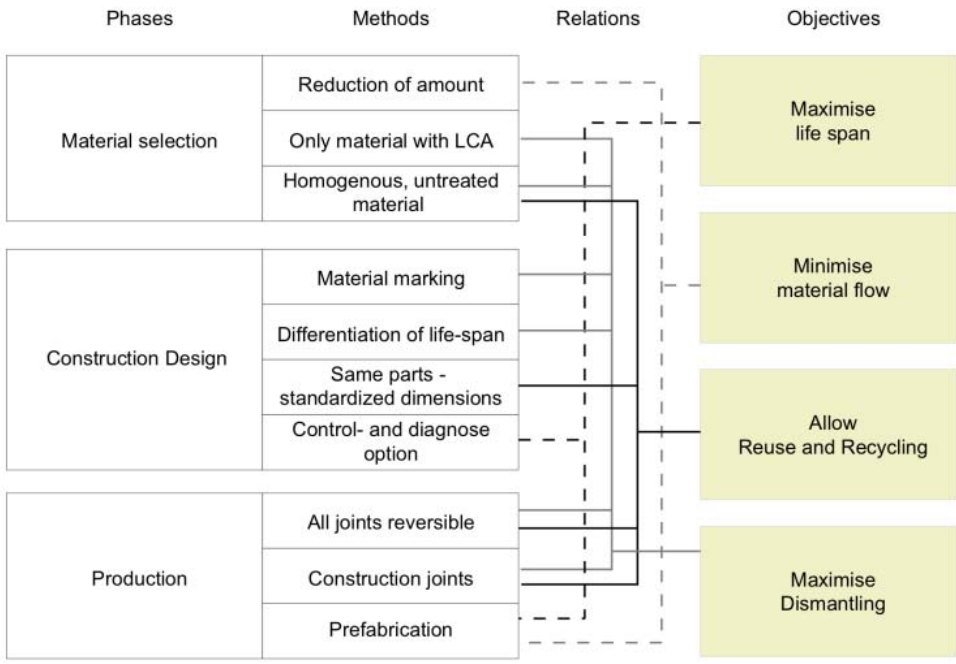


Figure 3-4 Robust construction engineering phases and interrelation with sustainability objectives (König) [29]

Table 3-2 Detailed analysis of robust engineering framework (le Roux, Ott)

Phases	Methods	TES Parameter	Result
Material selection	Reduction of amount	Distance of studs, insulation thickness	Lower physical mass, or insulation
	Only material with LCA data	PEFC or FSC origin	Sustainable forestry
	Homogenous material	No glue, binders etc., no compounds and mixtures	Declared waste streaming
Construction Design	Material marking	Detailed specification and product selection	Documentation for dismantling planning
	Differentiation of life-span	Construction principles & durable external layers	Appropriate service life
	Same parts, standardized dimensions	Reduced variety	Use of semi-finished products
	Monitor and diagnose option	Maintenance for durability in use phase	Prolonged service life
Production	Reversible joints	Screws as fasteners or connectors, sealing layers	Easier assembly and disassembly
	Construction joints	Tie-back anchoring	Easier assembly and disassembly
	Off-site production and prefabrication	High level of prefabrication	Reduce on-site work and waste
	Objectives	**Criteria**	
	Minimise material flow	Material flow analysis, carbon footprint	
	Maximise Dismantling	Modularity, structural fastening	
	Allow Reuse and Recycling	Documentation, standardisation	
	Maximise life span	Economic service life, remaining service life	

Definition: *Economic service life* is the remaining useful life of an asset that results in the minimum annual equivalent cost.

3.3.2 Differentiated smartTES components and materials

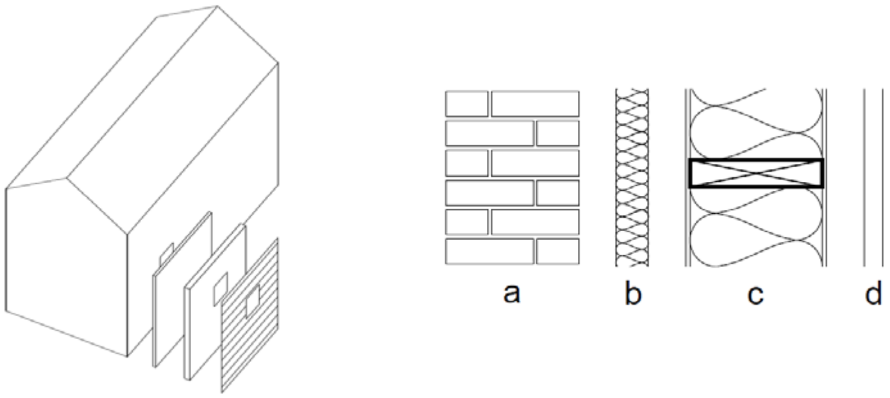


Figure 3-5 functional layers of the smartTES element (Ott)

The functional properties of all of the layers of the smartTES element are pre-defined, and the essential principles are defined to ensure the consistent design characteristics of this facade construction. SmartTES is a self-supporting facade structure similar to semi-balloon framed timber structures with support for vertical loads and horizontal anchoring against wind loads on each floor level. Each element has a structural framework and within this framework there is insulation which improves thermal properties of the existing exterior walls. The framework enclosure is necessary for structural bracing and has functional properties for the element to provide moisture safety, wind- and airtightness. For safety reasons specific panelling layers for fire safety can be applied. These mineral-based layers encapsulate and protect the insulation and structural parts of the elements.

The constant and variable components of the system are set as input dimensions and represent the subgroup of the *TES core* and the *Adaption layer* described in the published article about construction principles of TES.[30] The structure of the timber framework consists of timber studs that are positioned in a regular distance and butt-joint perpendicular to sill-beam and wall-plate. On the side of the element facing towards the building interior a panelling is applied for structural and airtightness reasons. Towards the outside surface a mineral- or wood-based panel is fixed. A gypsum fibre board is optional for a fire safety layer. The partition cavities will be filled with thermal insulation like cellulose fibre.

Table 3-3 Detailed matrix of a smartTES system with its core parts highlighted (Ott)

Functions		Possible implementation (options)	Additional functions in building classes 4 + 5	Options in building classes 4 + 5
Adaption layer	Insulation of adaption layer	loose fill insulation	with combustible insulation: fire stops around window	mineral wool strip
Thermal protection (TES core)	inner panelling (air tightening)	wood product panel and fasteners	only elements with enclosing function: inner panelling non-combustible (encapsulation)	Non-combustible: (e.g. gypsum fibre board)
	thermal insulation	loose fill insulation		
		insulation mat/roll		
	structure	construction timber and fasteners		
		other types of studs		
	outer panelling (wind tightening)	wood product panel and fasteners	outer panelling non-combustible (encapsulation)	gypsum fibre board
Weather protection	first waterproof layer	ETICS or facade cladding system	horizontal fire stops	sheet metal at horizontal joint
	ventilation layer (not ETICS)	wood or metal substructure system		
	second waterproof layer	necessary when first layer is improper		
Load transfer	structure for elements	coupling beam + fastener		
	horizontal wind loads	fasteners in timber framework and fasteners for elements with coupling beam		
	vertical dead load	Existing floor slab		
		concrete foundation		
		brackets and fasteners		
		cranking cantilever		
		suspended fixation at the element head		
Sealing	sealing horizontal joint	butt-joint sealing (e.g. EPDM ropes)	storey-wise fire stops between elements	non-combustible boards at horizontal joint
	sealing vertical joint	butt-joint sealing	continuous encapsulation	non-combustible underlayment of encapsulation
	sealing of roof overhang joint	air tightening membrane glued with existing masonry or plastered sealing strip		
	sealing of foundation joint	air tightening membrane glued with existing masonry or plastered sealing strip		

3.3.3 Durability and life-span concept

For life cycle durability and service life, only qualitative empirical values can be derived from existing structures e.g. from the predicted lifetime of dry wooden walls. No composite materials have so far been specified in the structural composition of the of rule-compliant TES elements. The only exceptions are the window sill and the sealing of the window frame. A selective dismantling process is possible on the element level on-site, a demolition is not necessary. All joints between the existing building and the smartTES are done by screws. Entire elements can be disassembled and transported for further waste management. The layers and timber framework of individual elements have to be separated and recycled off-site. The joints between the framework and layers of the element are durable and e.g. staples, nails are reversible only to a limited extent.

The aim is to demonstrate appropriate layer compositions instead of detailing smaller parts of the timber facade system. This assumption can be explained by considering the influence of the joint part in relation to the element area. A basic assumption is an average small facade of a 4 storey town house building with eight apartments. The length of all horizontal joints is roughly 320 – 520 meters including the length of the basement and the roof eaves. This sums up to an amount of 2,2 to 3,5 m³ of wood required for all horizontal joints plus ten percent for all vertical joints. Assuming that the average facade area is about 450 m², only 0,005 m³ of wood per square meter of the facade is needed for the element joints. The smartTES element itself requires about 0,036 m³ of wood per square meter.

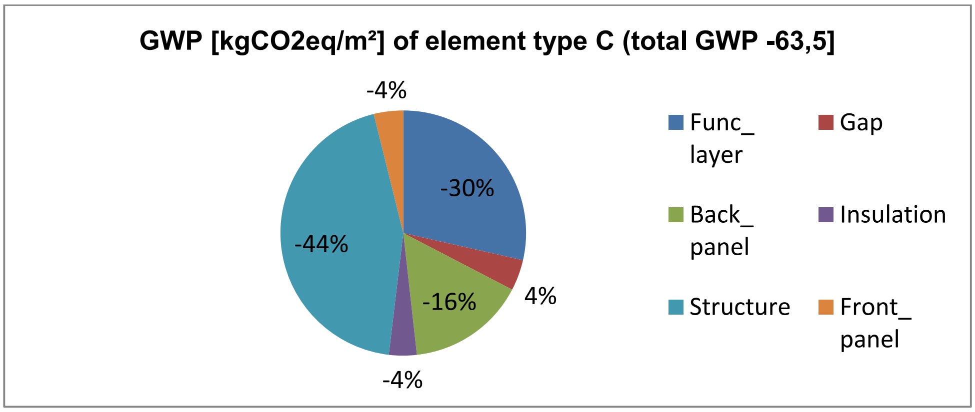


Figure 3-6 Global Warming Potential of element type C: Total GWP -63,5 kgCO2eq/m² (Ott)

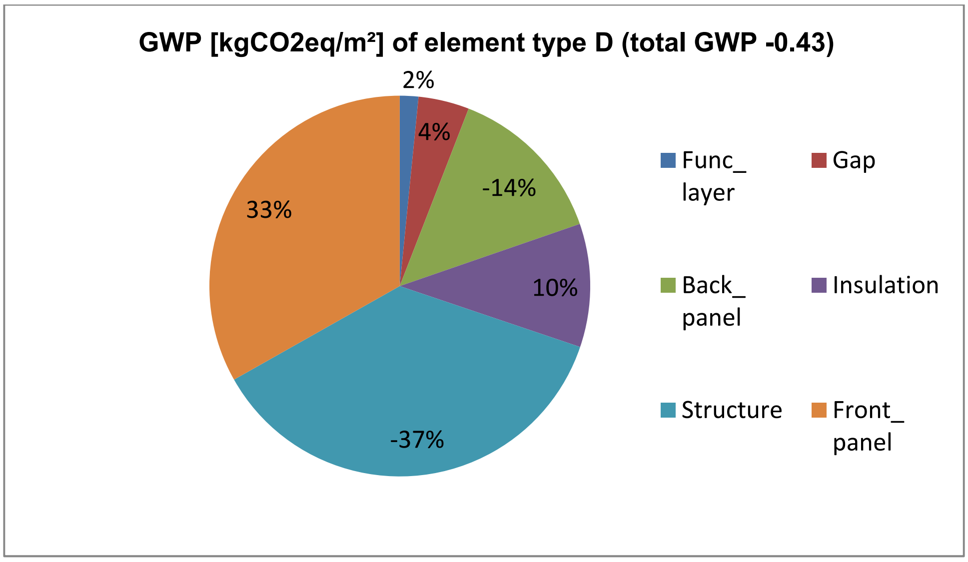


Figure 3-7 Global Warming Potential of element type C: Total GWP -0,43 kgCO2eq/m² (Ott)

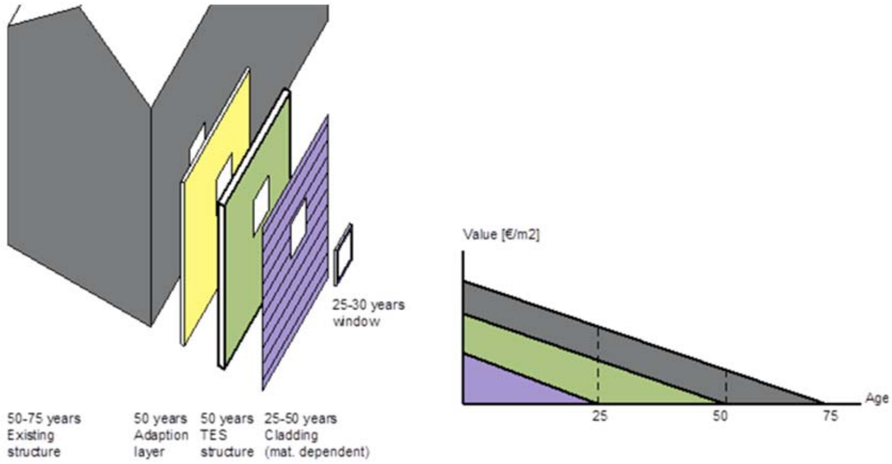


Figure 3-8 Differentiation of life span of smartTES element layers (Ott)

It is shown as an example that it is more beneficial from an LCA perspective to optimize the load-bearing structure of the element. The shape of the joint has a greater influence on the construction process and the later dismantling and material recovery at the end of life. These other objectives are integral in the whole life-cycle approach, and in particular in the development of the system details.

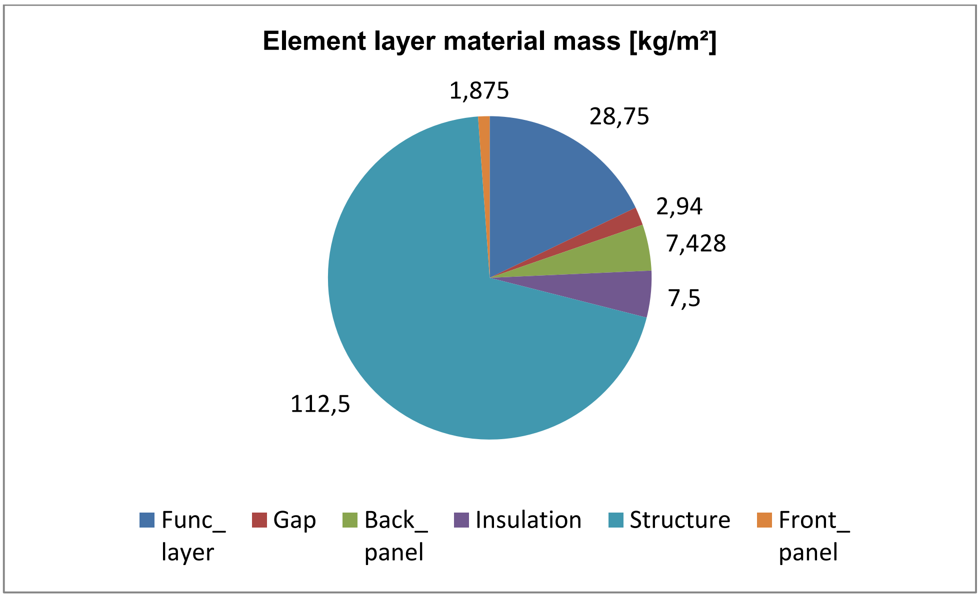


Figure 3-9 Mass distribution of an exemplary TES element (Ott)

Further goals are to maximize the lifespan of important components such as the primary structure, and give ability to reuse and recycling, as well as maximizing the dismantling. This is necessary to a higher degree for the exterior parts and layers. Compare the different life spans of layers TES layers with BmVBS tables with construction product specific life spans.[31] The durability of the wooden elements and the protection of the structure against climate exposure are done in compliance with normal hygrothermal requirements and moisture management in closed timber frame components. Thus the smartTES elements fulfil the requirements of use class 1, in which the wood or wood-based product is concealed inside a construction, and not exposed to the weather and risk of wetting.[32]

3.4 Examples of LCA calculations

3.4.1 TUM “LCA Toolbox” excel spreadsheet

Life cycle calculations are complex and require a high consistency of the data; otherwise the result can be hardly compared and certainly not optimized. Therefore an Excel-based LCA-tool is developed for the calculations on SmartTES elements which carry out consistent calculation.

Basic principles of the excel spreadsheet follow the rules how to calculate the impact of different parts of the functional unit. Each layer or part is broken down to the mass amount for the life cycle inventory. The mass of each part is multiplied with the specific indicators for primary energy and greenhouse gas emissions from the database. Necessary information consists of various sources. First of all there is the product database with available EPD or generic environmental data of different construction materials. This database is already implemented in the LCA-Toolbox and can be used. The tool is open for a variety of databases. Within one calculation procedure the database cannot changed and has to be consistent form one source. The information in the database also contains other data about the material properties, like material density and lambda value.

Additional information of the construction cross section is needed as well. The layer material and the layer thickness have to be put in as well as other geometrical data of the timber framework. Calculation of the mass quantity of materials is implemented for 1 m² of facade element. The input parameters are the material type, his density, and the layer thickness.

The mass transposition for the inventory, u-value calculation and the application of material indicators to all inventory positions is done automatically. Calculation of the environmental impact is done by multiplying the quantity of material with different indicators form the LCA database.

Calculation of total environmental impact sums up all layers form an element cross section and all life cycle modules.

The final result is available in different tables, which contain input information from the LCI and allow a transparent documentation. Further parts from the LCIA are also available as tables, like the greenhouse gas emissions table. The output is shown as total sum and additionally in a layer break down structure which allows to analysing impact of different material layers.

The Excel programming behind the toolbox interface is done in Excel 2010 and uses Visual Basic programming. For detailed information about the programming please contact the German partner, TU München, Chair for timber structures and building construction.

3.4.2 LCA Toolbox data definitions

The selected database for environmental indicators is the Ökobau.dat 2010 and specific EPDs for construction products.[33][34] The database for impact calculations is the heart of the LCA Toolbox (**Figure 3-10**). On one hand side the input data defines the output on material mass and material flow. On the other hand side the database of environmental impact data for each material has an important influence on LCIA results.

www.nachhaltigesbauen.de/oekobaudat/oekobaudat_data/oekobaudat2011/processes_renamed/2.10.01_Holzfaserdaemmplatte_(Nassverfahren).xml

Datensatz: 2.10.01 Holzfaserdämmplatte (Nassverfahren); 200 kg/m3 (de)

Inhalt: Datensatzinformation - Modellierung und Validierung - Umweltindikatoren

Datensatzinformation

Kerninformation des Datensatzes

Geographische Repräsentativität	DE
Referenzjahr	2000
Name	Basisname; Technische Kennwerte/ Eigenschaften 2.10.01 Holzfaserdämmplatte (Nassverfahren); 200 kg/m3
Technisches Anwendungsgebiet	Leichtplatten mit 155-170 kg/m3, Trittschalldämmplatte 250 kg/m3 Dicken bis 25 mm je Lage, 1250 x 2500 mm
Referenzfluss (Flussdatensatz)	Holzfaserplatte (m3)
Menge	1 m3 (Volumen)
Anwendungshinweis für Datensatz	Der vorliegende Datensatz ist bereits mit einem Sicherheitszuschlag von 10% auf die Ergebnisse versehen, da kein unabhängiges Review vorliegt. Das Umweltprofil beinhaltet die Aufwendungen für die Lebenszyklus-Stadien "Cradle to Gate". Es basiert hauptsächlich auf Literaturrecherchen.
Gliederung Produktgruppe (GaBiCategories)	Klassifizierung / Ebene / Ebene Bauindustrie / Isoliermaterial / Holzfasern
	Urheberrecht? Ja Eigner des Datensatzes (contact data set) PE INTERNATIONAL

Quantitative Referenz

Referenzfluss (Name und Einheit)	Holzfaserplatte (m3) - m3 (Volumen)

Zeitliche Repräsentativität

Figure 3-10 Screenshot of a generic dataset of a wood fibre insulation board from ökobau.dat 2011

A1 Germany (data based on Ökobau.dat usw., State: XX.2010)

Germany (data based	EN (unified names)	Density [kg/m3]	λ [W/mK]	PER [MJ/m³]	PENR [MJ/m³]	GWPT [kg CO2 eqv./m³]
Dämmstoffe	EPS	15	0,04	6,4	1369	45,8
Insulation	EPS (ETIC)	25	0,04	11,8	2662	86,9
	glass wool	20	0,035	72,32	1621,55	100,01
	LCFI (loose-fill cellulose insulation)	45	0,04	36,9	186,75	-29,385
	mineral wool	30	0,035	644	475	20,60
	mineral wool (ETIC)	46	0,035	27,3	929	68,80
	*phenolic resin					
	*Polyurethan (PUR/PIR)			46,6	2760	133,47
	wood fibre soft	55	0,039			
Struktur	*plywood, PF-bound, wet					
Structure	*plywood, UF-bound, dry					
(primär)	glue laminated timber, wet	450	0,13	10591	5958	-751,00
(primary)	glue laminated timber, dry	450	0,13	10591	5958	-751,00
	hybrid beam (FJI)	845,54	0,0691			
	LVL	480	0,13	16083	13499	-307,00
	*solid wood, softwood, air-dried, planed					
	*solid wood, softwood, air-dried, raw					
	solid wood, softwood, kiln-dried, planed	529	0,13	10800	5144	-818,00
	*cross laminated timber					
Beplankung	building board	1300	0,3	2236,3	7095	636,9
Cladding	*cement fibre board					

Figure 3-11 Screenshot of LCA database with different materials and their properties (Ott)

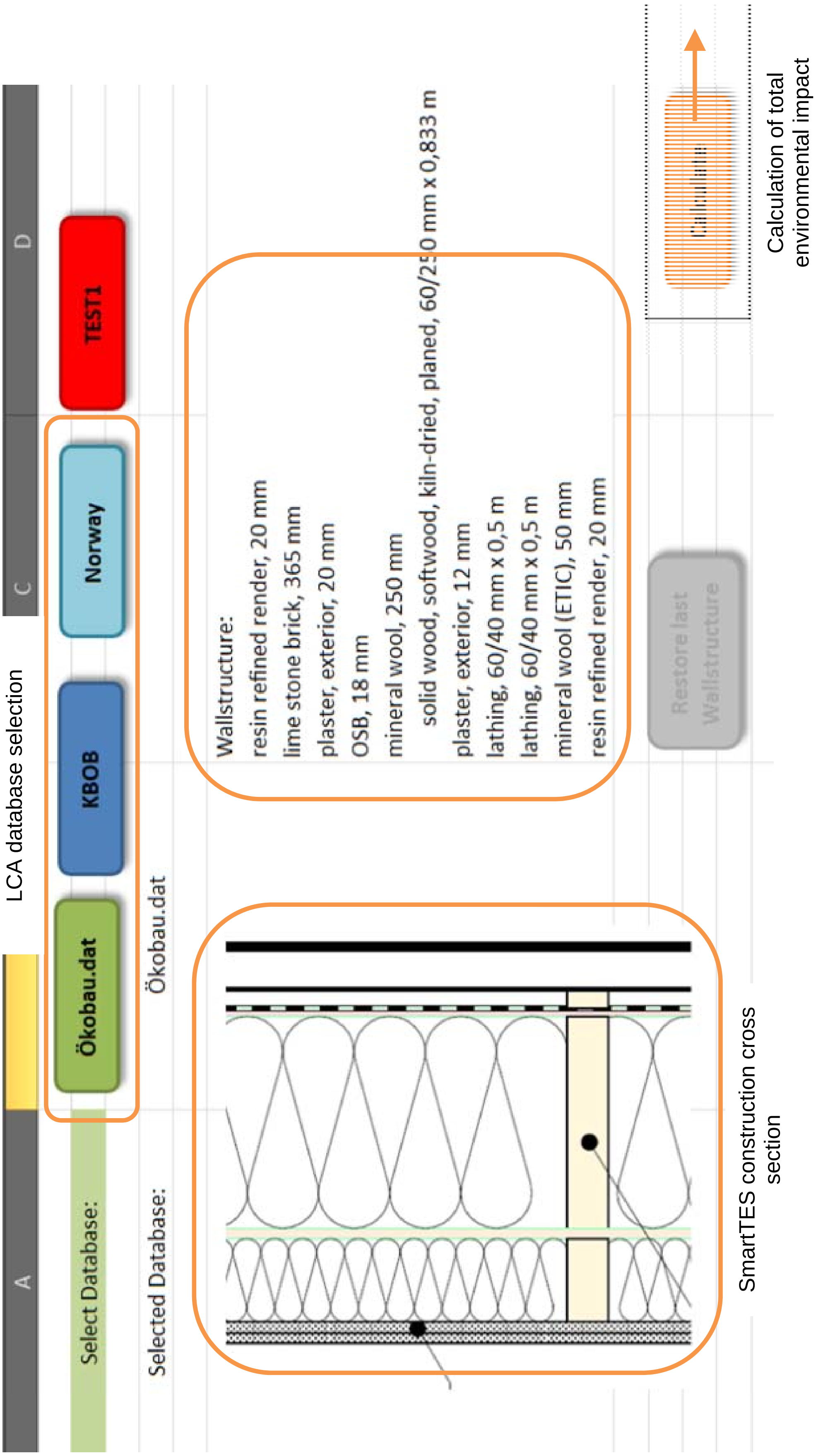


Figure 3-12 Screenshot of the main calculation worksheet (Ott)

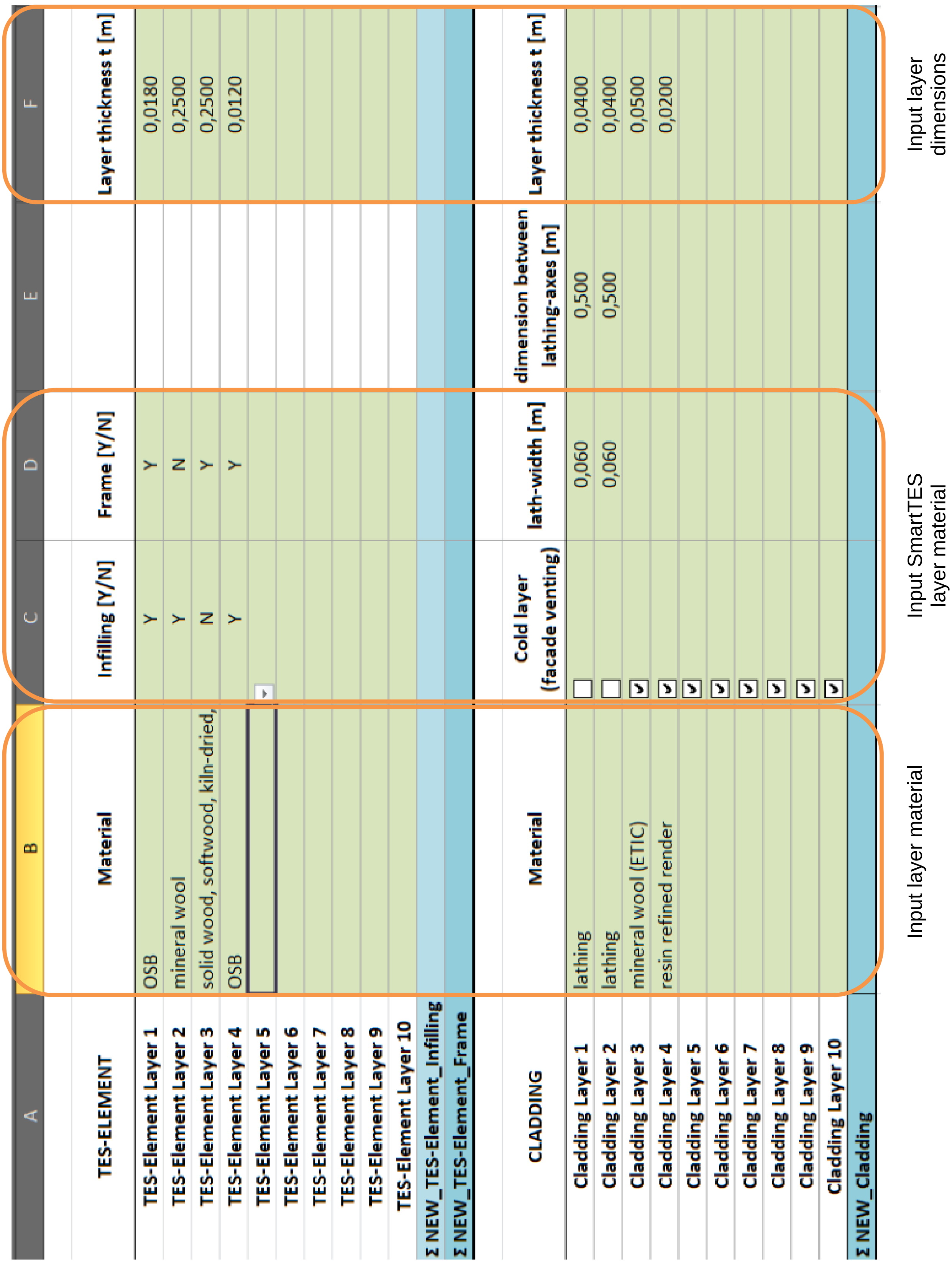


Figure 3-13 Screenshot shows selection criteria and input option of the worksheet (Ott)

U-Value					
TES-Element	Frame width [m]	0,060	R_si_tot	0,130	
	Dimension between frame-axes [m]	0,833	R_se_tot	0,040	
	Ratio of frame	0,072	R_si_tes	0,130	
	Ratio of filling	0,928	R_se_tes	0,040	
	u_total [W/m²K]	0,1239			
	u_element [W/m²K]	0,1411	U-value calculation		

DIN EN ISO 6946:2007	upwards	horizontal (≤ ±30°)	downwards
R_si	0,100	0,13	0,17
R_se	0,040	0,04	0,04

Surface resistance (m2.K/W)

Environmental impact results

	Stock	TES-Element	Cladding	TOTAL	BM ETICS
PER [MJ/m²]	29,509	0,000	105,054	134,56	927,00
PENR [MJ/m²]	644,903	0,000	96,218	741,12	927,00
PERM [MJ/m²]	0,000	0,000	0,000	0,00	927,00
PERE [MJ/m²]	0,000	0,000	0,000	0,00	927,00
Carbon storage [kg CO_2 eqv./m²]	0,000	0,000	8,650	8,65	48,50
GWPT [kg CO2 eqv./m²]	78,200	0,000	-4,395	73,80	48,50

Calculation of values for different insulation thicknesses			
Initial value [m]	Step size	variated layer, frame	variated layer, filling
0,050	0,050	TES-Element Layer 2	TES-Element Layer 3
initial-value: 0,05	stepwidth: 0,05	target-value: 0,5	thickness: 0,5

Calculate

Total							
Thickness of insulation t_insu [m]	U-Value [W/m²K]	PER [MJ/m2]	PENR [MJ/m2]	GWPT [kg CO_2 eqv./m²]	Carbon storage [kg CO2 eqv./m2]	PERM [MJ/m²]	PERE [MJ/m²]
0,05	0,160	-1879,132	-220,418	225,324	-159,320		
0,10	0,149	-1375,708	19,967	187,444	-117,328		

Figure 3-14 Screenshot of results table of LCA toolbox (Ott)

3.5 Case studies for layer composition variations

Case studies are used for screening the environmental impact of SmartTES. A screening will not provide full data and is used to improve a product by getting insight in some of its properties.

The cases come from Finland, Germany and Norway. All cases differ in dimension and material composition from each other. This allows a broad overview on different versions. It is expected, that the results are deviated and show the full spectrum of outputs.

The cases are real built projects and the layering and dimensioning is according to the regulations. These examples and their results are helpful for the industry, because they provide insight in best practice solutions.

Case studies have been made based on nine different TES wall constructions that have already been implemented in different projects. These projects were in Germany, Norway and Finland (**Table 3-4**). The thickness of the insulation, which is applied with these elements, varies between 200 and 400 mm. The thickness of the additional adaption layer is between another 50 to 80 mm. The smartTES cross-sections have resulting U values of 0.14 to 0.24 W/m²K. Together with the existing walls thermal properties, the total U-values after refurbishment can thus be reduced down to 0.10 W/m²K. The heating energy consumption of existing buildings can be reduced to the range of retrofit passive houses.

All TES elements compared in nine cases have the similar layer structures; only the functional layer is not included in all cases. Soft insulation is used for heat insulation and to compensate the gap. The supporting structure is made of solid wood or wood-based materials. The back side panelling requires only airtightness. The front side usually braces the element and additionally meet fire protection requirements on the front in the **Cases A, D, E, F, G** and **H**.

An overview of different layers (**Table 3-5**) shows the types of materials used in the case studies. This typical material related information can be used for first rough assumptions on the environmental impact of the facades. The origin of resources is used as indicator for first guess. The **Cases C, E, G,** and **I** have insulation from renewable resources or from recycling material. The **Case I** has front paneling from wood-based products. **Cases A** and **I** have additional functional layers which can make the final result worse.

Table 3-4 properties of TES elements for nine case studies (Ott).

A	***OSLO***		
	Position	*Material description*	*Dimension [m]*
1	functional layer	gypsum fibre board	0,025
2	gap	mineral wool	0,098
3	back_panelling	OSB	0,0125
4	insulation	mineral wool	0,25
5	structure	glue laminated timber, dry	0,25
6	front_panelling	wood fibre board, soft	0,125
	U-value (element)	0,136 W/m²K	

B	***OULU***		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	Soft mineral wool	0,05
3	back_panelling	plywood (and air barrier paper)	0,09
4	insulation	glass mineral wool 200+50mm	0,25
5	structure	solid wood, softwood, kiln-dried	0,25
6	front_panelling	cement fibre board	0,008
	U-value (element)	0,136 W/m²K	

C	***RISOR***		
	Position	*Material description*	*Dimension [m]*
1	functional layer	OSB	0,022
2	gap	mineral wool	0,138
3	back_panelling	OSB	0,012
4	insulation	wood fibre insulation	0,198
5	structure	solid wood, softwood, kiln-dried	0,198
6	front_panelling	wood fibre board, soft	0,019
	U-value (element)	0,179 W/m²K	

D	***RIIHIMÄKI***		
	Position	*Material description*	*Dimension [m]*
1	functional layer	TYVEK	0,0003
2	gap	Soft mineral wool,	0,1
3	back_panelling	Spruce plywood, UF-bound, dry	0,009
4	insulation	mineral wool	0,3
5	structure	LVL 39mm x 300mm	0,3
6	front_panelling	Aquapanel cement fibre board	0,0125
	U-value (element)	0,117 W/m²K	

E	***FIRETEST, Germany***		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	LCFI loose-fill cellulose insulation	0,08
3	back_panelling	OSB	0,012
4	insulation	LCFI loose-fill cellulose insulation	0,2
5	structure	solid wood, softwood, kiln-dried	0,2
6	front_panelling	gypsum fibre board	0,018
	U-value (element)	0,197 W/m²K	

F	**MUNICH**		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	mineral wool	0,08
3	back_panelling	wood fibre board, hard	0,004
4	insulation	mineral wool	0,2
5	structure	solid wood, softwood, kiln-dried	0,2
6	front_panelling	gypsum fibre board	0,015
	U-value (element)	0,177 W/m²K	

G	***AUGSBURG***		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	LCFI loose-fill cellulose insulation	0,05
3	back_panelling	OSB	0,01
4	insulation	LCFI loose-fill cellulose insulation	0,2
5	structure	solid wood, softwood, kiln-dried	0,2
6	front_panelling	gypsum fibre board	0,015
	U-value (element)	0,197 W/m²K	

H	***BUCHLOE***		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	mineral wool	0,08
3	back_panelling	OSB	0,01
4	insulation	mineral wool	0,3
5	structure	glue laminated timber, dry	0,3
6	front_panelling	gypsum fibre board	0,018
	U-value (element)	0,120 W/m²K	

I	***HANNOVER***		
	Position	*Material description*	*Dimension [m]*
1	functional layer		
2	gap	LCFI loose-fill cellulose insulation	0,05
3	back_panelling	OSB	0,01
4	insulation	LCFI loose-fill cellulose insulation	0,18
5	structure	solid wood, softwood, kiln-dried	0,18
6	front_panelling	wood fibre board, soft	0,06
	U-value (element)	0,167 W/m²K	

Table 3-5 Overview on the criteria for different layers of SmartTES.

Layer	*Case studies*	*Type of material*
Functional layer	**A; B; C; D**	airtightening foil or board
Back panelling	all	wood based panels
Framework	all	wood based studs
Insulation	**A; B; D; F; H**	mineral or glass wool insulation
	E; G; I	loose fill cellulose fibre insulation
	C	wood fibre insulation
Front panelling	**A; D; E; F; G; H**	mineral-based building board (gypsum based or cement bound)
	A; C; I	wood based panels

3.5.1 Case study results for TES elements

The results focus on the material inputs and their related burdens and benefits. A major goal is to compare the full TES systems with the benchmark of conventional retrofit systems for facades. Assessment is also made on the basis of the comparison of inflows of Primary Energy and the outflow indicators of Global Warming Potential. Moreover, very good and very poor TES solutions can be identified and better compared. The averages for the primary energy content and the global warming potential give important indicative values of the performance of the entire system. They are also orientation values for the extremes of the distribution and the degree of deviation.

Overall results

The primary energy expenditure for smartTES production is high, if you look at the pure numbers (**Figure 3-15**). The ratio of renewable primary energy (PER) versus non-renewable primary energy (PENR) content is on average 815 MJ PER to 603 MJ PENR. Compared to that, the primary energy content of ETICS are rather small, they have a ratio of 7 MJ PER versus 331 MJ PENR.

The renewable primary energy content of smartTES also contains the portion of the calorific value of the wood material in addition to the energy of production; it is therefore similar to, or higher than, the non-renewable primary energy. The calorific value of a square meter of smartTES is at least 212 MJ or 55 kWh, and thus this portion is more than a quarter of the average renewable primary energy demand. For the cases dimension of insulation starting at about 200 mm the structure has enough reserves for dead load, when the standard application facade insulation is considered. No other load is relevant for the dimensioning of the studs of the elements. On the other hand side there is a correlation between the dimension of the cross section and the renewable primary energy content.

The smartTES facades have a carbon sequestration potential of an average 50 kgCO2eq./m² which is almost constant between different versions. The GWP of nine different versions of smartTES is on average at -35 kgCO2eq.

In **Case A** for example, it is apparent that there are positive and negative values for global warming potential in the TES element layers composition. The functional layer and the insulation are on the positive ordinate axis because they do not have carbon storage in cradle to gate phase. The wood based materials from the back panels to the front panels are on the negative ordinate axis due to their carbon storage. They avoid carbon emissions and contribute to a reduction of global warming therefore they have a bonus expressed in negative values for the cradle to gate phase.

The GWP of nine different versions of smartTES is on average four times below the reference value of polystyrene-based ETICS. This clearly shows the main ecological advantages compared to the conventional and established facade insulation solutions with high U-values. Despite high primary energy consumption, the remaining GWP of TES is still lower than for ETICS. The need for improvement of resource efficiency in the production of smartTES elements and their component materials should be noted in particular. However, a more detailed examination of material properties and is needed for future TES Research & Development.

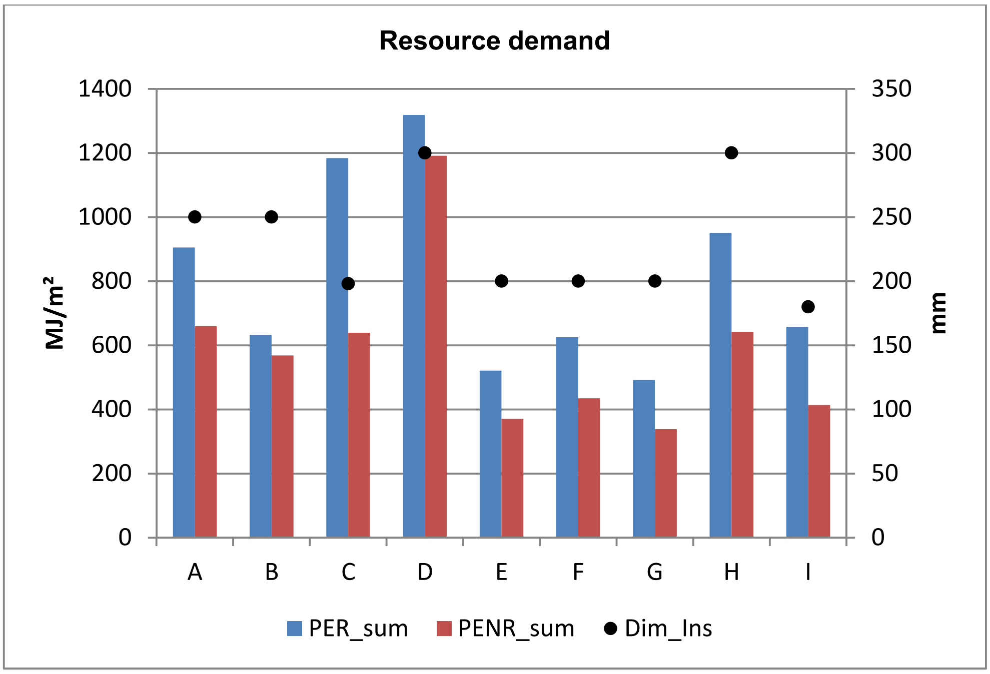


Figure 3-15 Resource demand of construction compared to thickness of insulation and smartTES element for each case study (Ott)

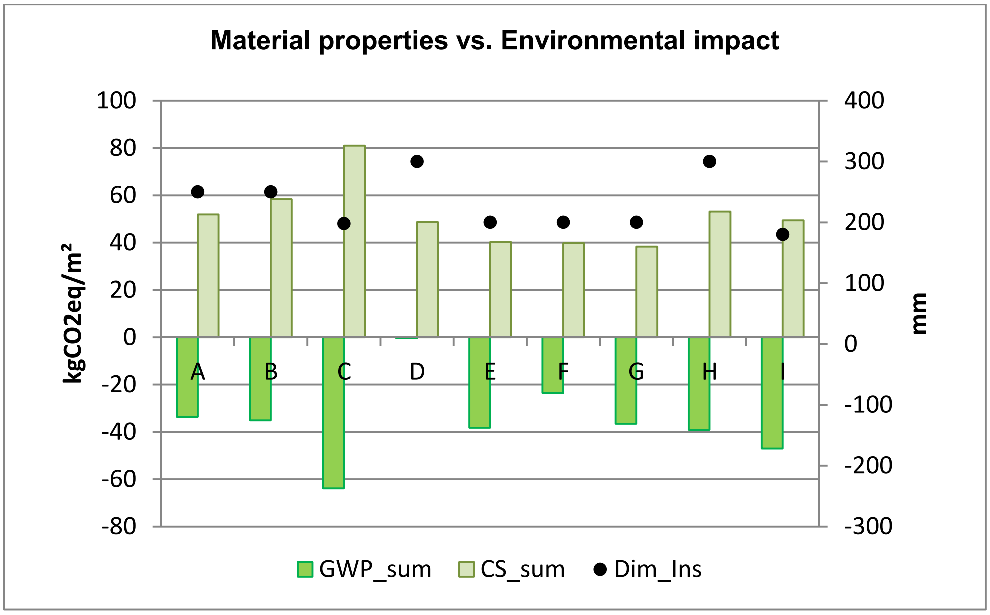


Figure 3-16 Environmental impact versus the benefit and compared to dimension of smartTES elements for each case study (Ott)

3.6 smartTES layers environmental impact in detail

The analysis of the element layering is a method for evaluation of environmental impact of parts and applied in the following detailed analysis. The inflow indicators by PER, and PENR and the outflows of GWP and carbon sequestration together with the outflows or emissions of GWP are individually calculated for each component layer. The correlation between the insulation dimension and the primary energy content is assessed to get a verification of the assumption that insulation layer thickness has a significant influence on environmental impact. The sensitivity of the influence of layer materials is checked in a dominance analysis to find the parameters which have the biggest influence on environmental impact. Finally the evenness of material compositions graphs show how important certain layers are on the end result and the level of environmental impact.

Table 3-6 Indicator overview of all nine examples with averages and standard deviation (Ott)

	Min	*Max*	*Average*	*SD*
PER	492.21	1318.37	815.38	275.74
PENR	338.27	1191.28	603.38	249.30
GWP	-0.43	-63.89	-33.78	16.67
CSeq	38.32	81.00	50.82	12.16

In principle, all layers are variable, with regard to the dimension as well as with regard to the materiality. In order to handle the possible diversity it is necessary to consider the requirements matrix and to ensure the correct choice of environmentally-friendly construction of the system. The choice of the layers in the context of the design principles makes it possible to evaluate them separately and to assess environmental impact of layers. The comparison of the individual inflows and outflows reveals how this parameterized layer affect the result of each indicator. Facades such as smartTES can avoid or replace materials with high environmental impact in contrast to other constructional parts of a building like foundations. This is not always a simple task for wood-based materials, because fasteners, adhesives, or encapsulating materials can influence the outcome (structural, safety, etc.). If the influence can be reduced the overall result will become more consistent in terms of environmental impacts.

It is expected that the insulation material and the studs have the highest proportions and the strongest influence on the distribution of primary energy. This can be confirmed from a general perspective with the numbers in **Figure 3-17** compared to **Figure 3-18**. There is also an expected correlation between the insulation thickness and the primary energy parameters. Regression analysis of the insulation thickness gives a linear R-squared = 0.62. There is a correlation between the PER and PENR and the u-value of the element cross section. Further it is expected that there is a strong negative CO2eq for GWP as mostly wood and wood-based materials are in use. This is true for almost all the facade versions that are investigated (compare **Figure 3-19** to **Figure 3-20**). Mainly the mineral based panelling of the smartTES front side will have some influence as well as non-renewable insulation. The range of GWP values is very low for the Back_Panel layers (back side panelling of timber framework). The Back_Panel layer is only thin regard the entire cross section. The front panelling layers (Front_Panel) has greater deviations in GWP, because requirements for fire protection or structural bracing define other material and dimension parameters. The carbon sequestration indicators are strong for all cases due to the significant amount of wood in all structural parts. Some examples have higher amounts of wood due to additional panelling and insulation of wood as is seen in **Case C**.

Looking closer at this analysis, there are some noteworthy features related to particular element production techniques and associated with the use of certain materials.

In facade in **Case C** has a functional layer facade as internal Layer1 (= shell) which is included for air tightening reasons. For this layer, there is a small reinforcing effect of GHG emission (comparison in
Figure 3-21**).**

In
Figure 3-21 the GWP also indicates a distinct greenhouse gas potential in the facade version of **Case D**, whereas the other versions all have a lesser proportion of the positive GWP variants. The same applies to the primary energy content from **Case D**. It should be noted that for static and structural reasons the load-bearing structure of these versions is laminated veneer lumber (LVL). This material has a similar production process to plywood products and in €CO2 there is an explanation for the high amount of GHG emissions, which come from production phase, not from the wood. “In plywood manufacturing, GHG emissions are distributed differently then saw timber manufacturing. In plywood manufacturing, adhesive and other raw materials have a big effect on the raw materials GHG emissions (approximately 50% of all GHG emissions).”[35]

The insulation material used is mineral-based. In sum, this leads to a below-average score overall impact categories. Highlighted for positive performance, especially **Cases C, H** and **I** show low GWP values. **Case H** has a good GWP value despite having large insulation thickness and anon-renewable insulation material. This is due to the high proportion of wood in the load-bearing structure. The layers have almost no greenhouse gas emissions with the exception of **Case H**, because it has a mineral based insulation and front panelling. **Case I** is very balanced overall component layers compared to other cases. Reason for this is a high amount of wooden products, avoidance of encapsulation layers from mineral based panels and recycled cellulose fibre as insulation material. There is also a spike from the insulation material in this diagram. Reason for this result is a high amount of GWP for the glass wool used.

The influence of insulation and its material is a significant burden while the influence of insulation thickness is comparable low.

The structural framework has a strong influence of the on the negative GWP while the panelling and the insulation do not have this (
Figure 3-22). The structure also has the highest deviation of all scores. The even distribution of the impacts of other layers, apart from the front panelling, is also apparent in the comparison of case studies (
Figure 3-22).

As mentioned before the LCA module A4-5 construction is based on a very general assumption. It is given that the module A4-5 equals 20-30% of the total impact of LCA module A1-3 product. In addition, the scenario A4 transport has a relatively high share in the module A4-5, approximately 30%. The other 60% can be allotted to scenario A5 construction works and construction waste in equal shares.

“*In the case of carbon efficiency, the main focus should be to reduce fossil greenhouse gas emissions, although biogenic GHG emissions can also be reduced from an energy saving perspective*.”[36]

Sawn timber has a small carbon footprint which is induced mainly by the manufacturing process and not by forestry and transportation, compares the findings of **€CO2 - Wood in carbon efficient construction**.

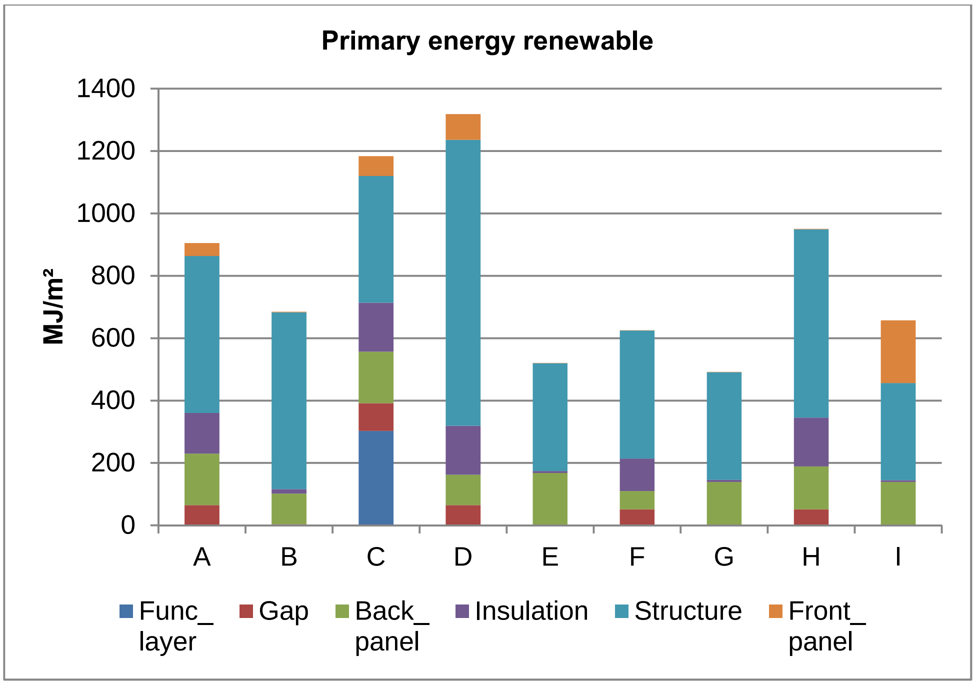


Figure 3-17 Renewable primary energy content of nine cases (Ott)

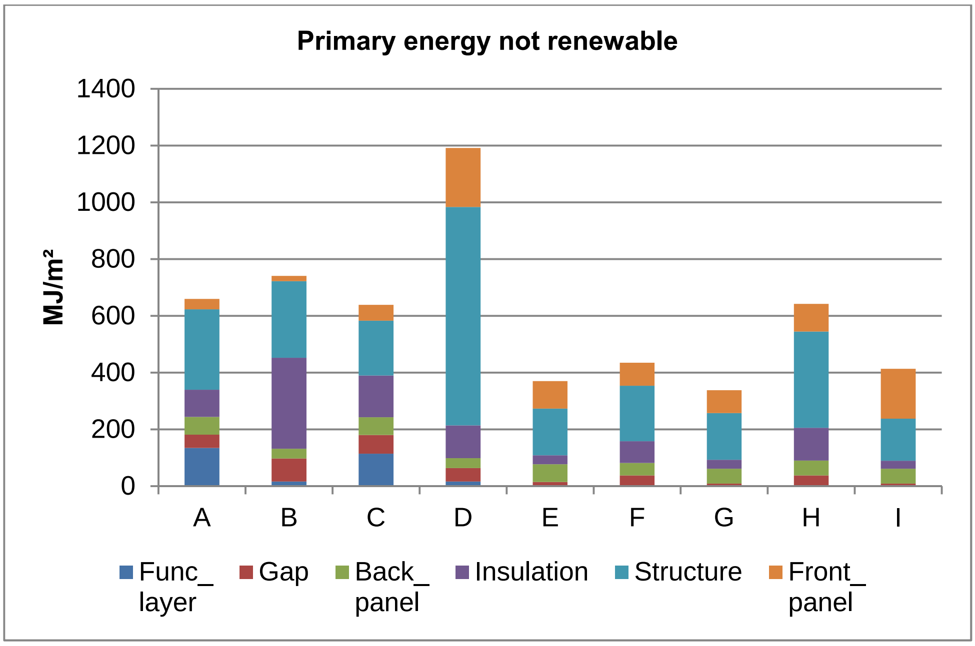


Figure 3-18 Non-renewable primary energy content (Ott)

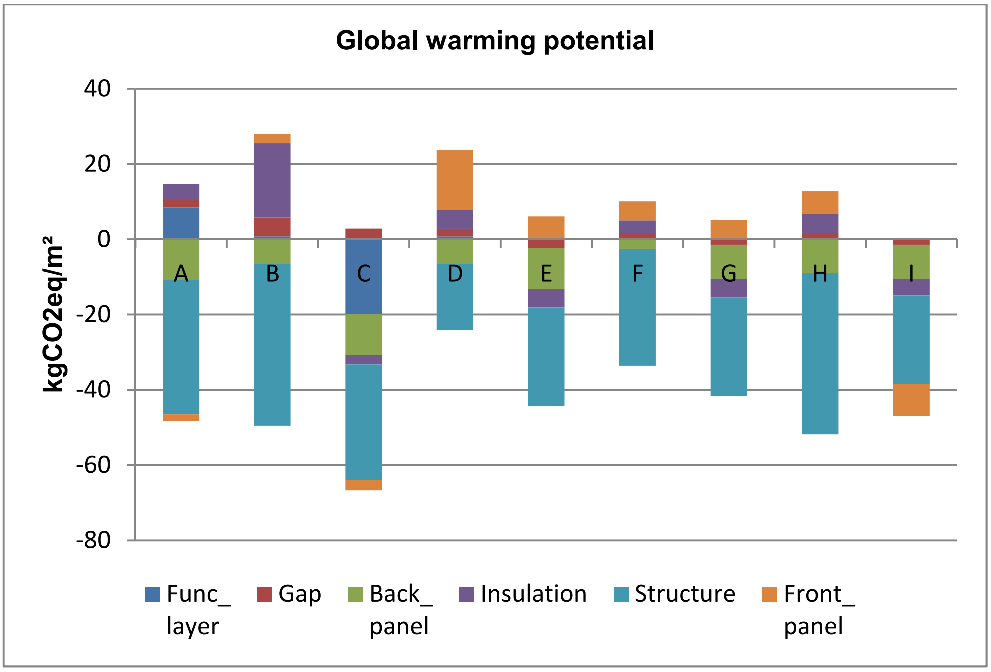


Figure 3-19 Global warming potential (Ott)

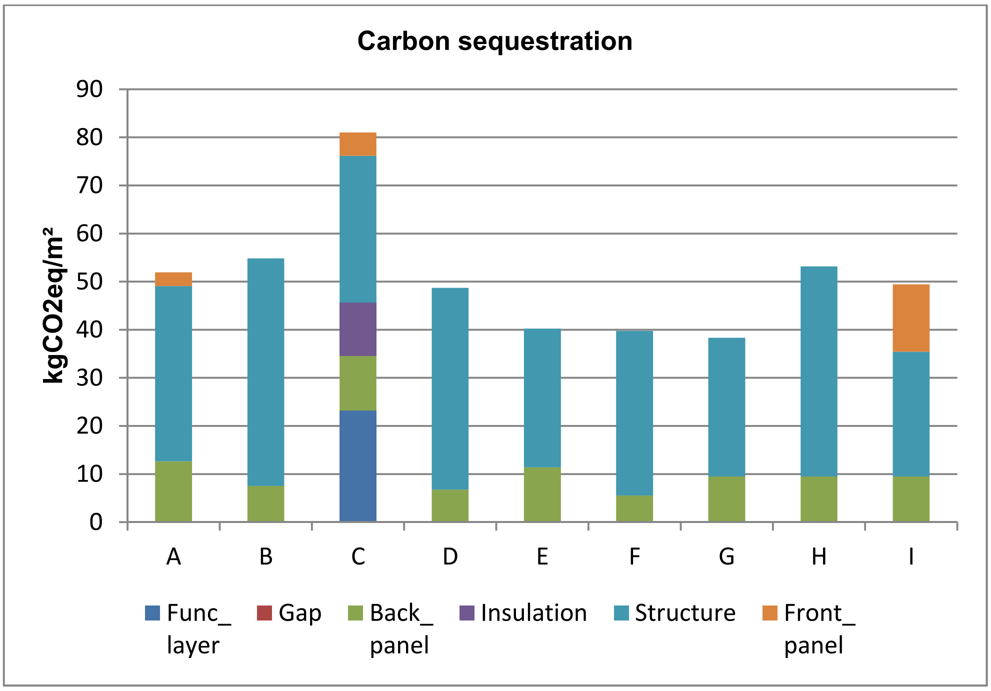
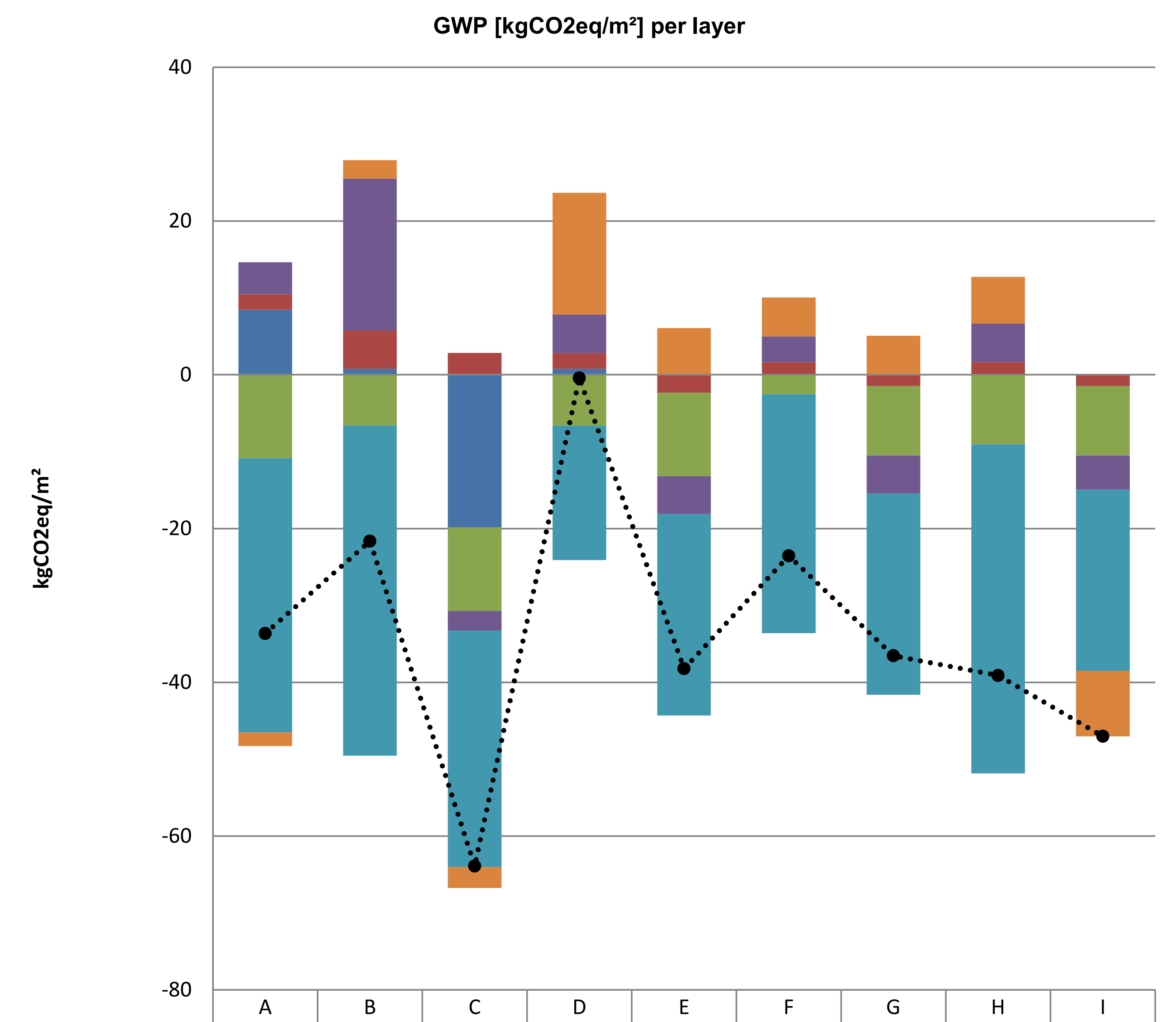


Figure 3-20 Carbon sequestration potential (Ott)



	A	B	C	D	E	F	G	H	I
Front_ panel	-1,77375	2,4057	-2,7	15,85	6,084	5,07	5,07	6,084	-8,514
Structure	-35,6725	-42,945	-30,7724	-17,499	-26,176	-31,084	-26,176	-42,807	-23,5584
Insulation	4,1715	19,750988	-2,550042	5,0058	-4,93668	3,3372	-4,93668	5,0058	-4,443012
Back_ panel	-10,836	-6,597	-10,84	-6,6	-10,836	-2,52	-9,03	-9,03	-9,03
Gap	2,0188	5,00025	2,8428	2,06	-2,3508	1,648	-1,46925	1,648	-1,46925
Func_ layer	8,45	0,7526884	-19,866	0,7526884					
GWP_sum	-33,64195	-21,63237	-63,88564	-0,430512	-38,21548	-23,5488	-36,54193	-39,0992	-47,01466

Figure 3-21 Global warming potential in detail compared to the total sum (Ott).

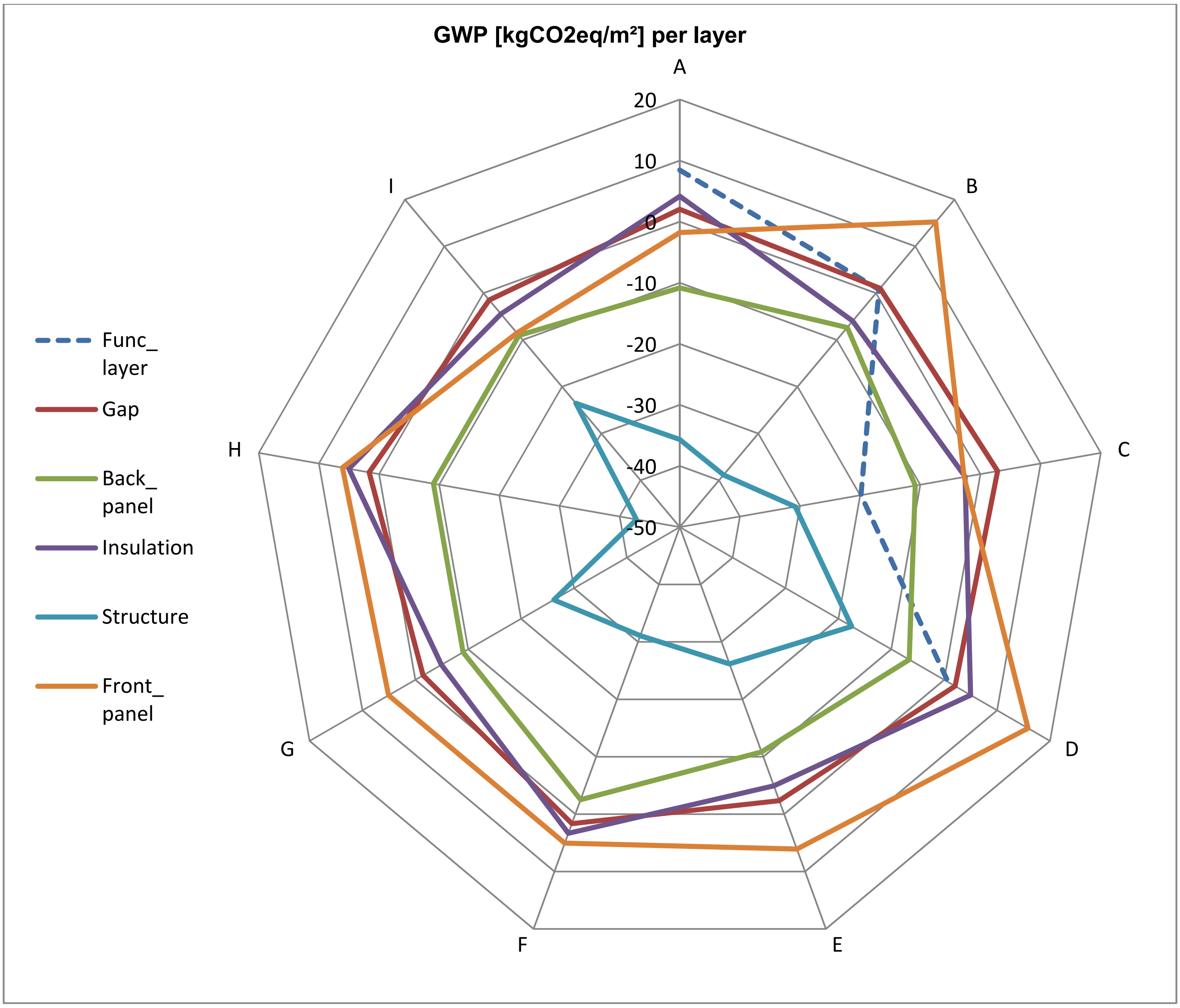


Figure 3-22 Dominance of GWP related to layers (Ott).

3.7 Conclusions

The smartTES system is analysed to reveal which of the features of modernization projects are most consistent and which features result from individual solutions. This inquiry is necessary to be able to use a catalogue of requirements for all projects as universally as possible. The dominant parts of the system do not have the highest environmental impacts like the timber framework as structure. Rather, they make a positive contribution to the environmental impact by saving a high percentage of carbon. This remains quite constant in various constructions, as the dominant shares are from renewable resources. But the correct selection of structure and insulation materials can influence the positive properties of smartTES Facade to a large extent.

To sum up, it can be stated only the front cladding and insulation can deteriorate the GWP balance because they have values on the high emission side of the GWP which is a positive figure. The wood framing and the panelling of the back are renewable materials with negative figures and absorb more CO2 than the production emits. The functional layer is not always required, but it can contribute a slightly negative influence on GWP. The environmental impact of the insulation layer in the adaption layer of the gap is in contrast, constant low and almost negligible.

All smartTES Facade solutions are relatively homogenous regarding their global warming potential. The deviations depend largely on the choice of material for the studs and the insulation, and are more obvious on the inflow side than on the impact. The panelling has only minor influence.

3.8 Summary

The eco-balance calculation tool developed by TU München for the smartTES facade elements will be expanded in the future with complementary information. It shall be extended to include previously disregarded components (e.g. anchoring bolts, foils, tapes), as well as to capture characteristic values for end-of-life scenarios. The cladding layer as well as integrated elements will be shown only by examples, because they are chosen individually for each project and they have separate EPDs or even ESDs, and therefore are kept outside the TES system boundary. Another interesting aspect is to gather a deeper insight into the necessary amount of energy and waste for off-site construction and the missing values for flows resulting from on-site processes. The assembly of a smartTES element wrap-around on existing buildings is very different from new building with timber constructions and will cause further environmental impacts that should be reduced.

3.9 References

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4. Conclusions and recommendations

4 Conclusions and recommendations

Sustainability Criteria and assessment guidelines

TES Energy Façade (Timber based Element System) is a facade retrofit solution which employs material efficient prefabrication, cost-effective and fast site assembly, and a lightweight energy efficient envelope, with low embodied energy from a high degree of renewable raw materials, a high degree of refurbished and recycled building components, and a durable solution for a cost-effective use phase with minimum end-of-life impacts and long service life. The characteristic property and intrinsic strength of TES is the improved energy efficiency and thermal comfort of the building envelope achieved with low structural material impacts (LCA), and the use of an innovative technology based on prefabricated.

The use TES for refurbishment has been shown to support the preconditions to achieve good environmental ratings, improved energy performance, and reduce life cycle impacts, with robust low-tech measures, observing detailed prescriptive criteria, and also analyzed with advanced LCA methodology. It is feasible and recommended to include a broad range of sustainability targets into a refurbishment project, and enhance the overall performance with project management, and with a bottom-up approach to end-user and stakeholder needs, and the application of specific tangible measures. The broader holistic view enables upfront integrated design to deliver a fit-for-use building, with durable environmental, economical, technical, social, functional and process quality.

Taking a system boundary approach to TES sustainability, an assessment framework is organized on a on a hierarchy of scales from global to specific - from the most global and abstract level of energy, to the most tangible and subjective level of the end-user, with the purpose of keeping social sustainability in focus, in order to offset the marginalization of the end user needs, when placing effort into the physical construction process. TES evaluation according to a hierarchical strategic framework follows a clear definition of responsibilities and representatives in the refurbishment design team. Each sphere of influence should be represented, e.g. land use, energy and end-users. By the transparent collaboration of representatives, both top-down policy and bottom-up agency can be met.

The scope of building level LCA includes the impacts of construction products and construction processes, but the loads on the surrounding community are effectively out the scope of assessment for an individual refurbishment project. Location and urban context determines the market value, feasibility, scope and usability of a project, which ultimately determines the service life, payback and benefits of a refurbishment investment. The limited scope of environmental assessment and the relation between project impacts and urban context implies a need for assessment tools beyond the system boundaries of LCA and building environmental ratings.

TES manufacturers will need to deliver the information required for reliable EPD’s, and case studies are needed to benchmark the building level LCA performance of refurbishments which include façade retrofits using TES. The current situation with TES sustainability is that comprehensive, specific, or typical EPD information for TES façade elements are not available, and that any material flow or embodied carbon analysis is reliant on generic information from sources with a range of values, and sometimes inconsistent data. Even with the EPD data that is available, one requires a building level life-cycle analysis to substantiate the claims of TES environmental performance, and a benchmark building level LCA with competing products, to judge the environmental assessment. With case studies at building and product level it is possible to demonstrate quantified aspects of TES environmental performance, and even so, the broader qualitative issues (social sustainability) and cost-efficiency targets are out of the scope of assessment.

Integrated modernization solutions

Sustainable retrofit must analyze each construction project from a life cycle perspective. It is to include alternative retrofit methods such as SmartTES. The environmental impact can be determined at the product level by material flow analysis and LCA methods. The previously recognized potential for optimization must be transformed into future, marketable products. More detailed studies on the long-term robustness of multifunctional wooden facades are required.

Deep retrofit with major changes in the building envelope as well as changes on the primary structure reach up to 50 % of embodied energy of the original existing substance. The End of Life of the material outflow can contribute to a reduction of embodied energy when recycling scenarios are applied. Consequently the share of this reduction is quiet low compared to the total outflow of embodied energy.

The application of TES elements adds new materials for the old, demolished materials. Among the fluxes are the energy flows for the manufacture and installation. On the input side appears high primary energy content, these are mainly bound to the material aspect of renewable resources. Which is a bonus for the end of life, because in a distant future, these bound resources can be accessed and utilized environmentally friendly. It requires a careful use of the material and embodied energy today while the future use has to remain at tolerable levels and should cause little environmental impact as possible. In particular, designers and wood contractors need to consider these potential problems in the project and product development.

It appears that renovation projects with TES produce a high outflow of materials and will therefore release more embodied energy. This means that TES tends to require deep retrofit actions. It is more likely related to bigger effort also on the material inflow side, because every removed construction component has to be replaced by a new component in order to make a building functional working. Seldom components are redundant and can be skipped after demolition. An additional amount of embodied energy is generated and changes the environmental impact. This is just a first impression based on the available data and analysis results. The possible relationships between restoration methods and scope cannot be determined without detailed analysis, for this further practical examples need to be studied and evaluated.

The potential for optimization must be transformed into future, marketable products. More detailed studies on the long-term robustness of multifunctional wooden facades are required.

Robust product engineering

The smartTES system is analyzed to reveal which of the features of modernization projects are most consistent and which features result from individual solutions. This inquiry is necessary to be able to use a catalogue of requirements for all projects as universally as possible. The dominant parts of the system do not have the highest environmental impacts like the timber framework as structure. Rather, they make a positive contribution to the environmental impact by saving a high percentage of carbon. This remains quite constant in various constructions, as the dominant shares are from renewable resources. But the correct selection of structure and insulation materials can influence the positive properties of smartTES Facade to a large extent.

To sum up, it can be stated only the front cladding and insulation can deteriorate the GWP balance because they have values on the high emission side of the GWP which is a positive figure. The wood framing and the paneling of the back are renewable materials with negative figures and absorb more CO2 than the production emits. The functional layer is not always required, but it can contribute a slightly negative influence on GWP. The environmental impact of the insulation layer in the adaption layer of the gap is in contrast, constant low and almost negligible.

All smartTES Facade solutions are relatively homogenous regarding their global warming potential. The deviations depend largely on the choice of material for the studs and the insulation, and are more obvious on the inflow side than on the impact. The paneling has only minor influence.

On a practical level, research is expected to deliver simple rules of thumb for the application and dissemination of focused sustainable product development. However, the realities of complex systems and the uncertainties of sustainability verification make it near impossible to come up with universal guidance. “Sustainability” is framed by the history of the built environment, traditions and culture, and is broad a concept as “Society”. Rather than expecting a calculation to deliver a simple answer, the decision maker should understand the principles behind the calculation, and come to a deeper understanding of the significance of the numbers. At the core of sustainability the target is to understand and recognize user needs: fitness of purpose is the goal for design. The numbers should recognize the subjectivity of added value. In the long term, sustainability principles aim to motivate a break from conservative norms, and contribute diversified retrofit strategies within evolving urban ecology. Society learns from stories of success and failure. Through sustainability analysis and ongoing monitoring there is potential to communicate successful and innovative projects to a broader audience.

Variations in LCA methodology and national database definitions of carbon storage in wooden products create significant differences in the results of LCA analysis. Future and transparent research is needed to establish a broad and reliable database for TES EPD’s and life cycle inventories and databases for LCA analysis.

The assumed end of life use and potential for extending the life of wooden products needs further development. Consensus in needed for the purpose of LCA comparisons, but more importantly, design decisions and timber components should anticipate the end of life phase, and enable the reuse of timber products. Product development is needed to create channels and a real market for timber reuse; otherwise the discussion on the LCA definitions for wood products will remain purely rhetorical positioning between construction material industry representatives.

5. Sustainability standards and glossary

5 Sustainability standards and glossary

5.1 European Standard development for Life Cycle Assessment

5.2 CEN/TC 350 “Sustainability of construction works”

In this series of standards, the environmental dimension of sustainability is limited to the assessment of environmental impacts and aspects of a building on the local, regional and global environment. The assessment is on Life Cycle Assessment and additional quantifiable environmental information expressed with quantified indicators. It excludes the assessment of a building’s influence on the environmental aspects and impacts of the local infrastructure beyond the area of the building site, and environmental impacts and aspects resulting from transportation of the users of the building. It also excludes environmental risk assessment.

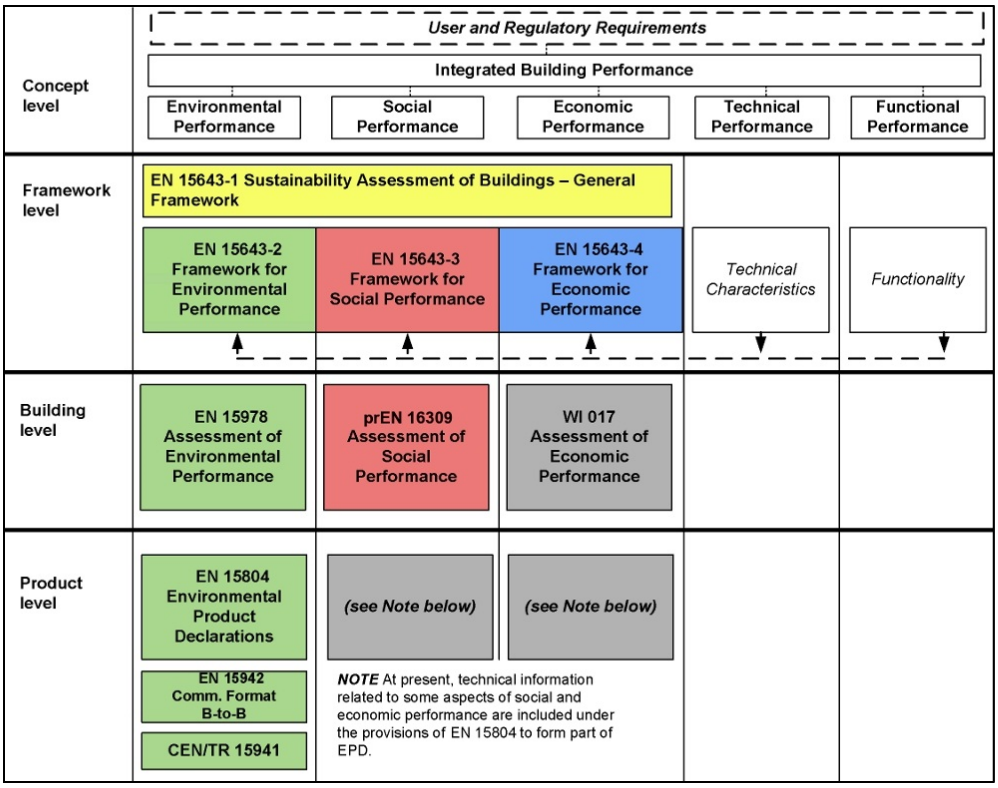

Figure 5-1 The work programme of CEN/TC 350 (AFNOR Normalisation)

5.2.1 Sustainability Framework EN 15643

5.2.2 EN 15978

The European Standard **EN 15978** Assessment of environmental performance of buildings specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building. The approach to the assessment covers all stages of the building life cycle and is based on data obtained from Environmental Product Declarations (EPD), their "information modules" (see prEN 15804) and, when appropriate, other information related to the environmental performance of the building as a whole.

5.2.3 Environmental product declarations EN 15804

5.2.4 EN 16485 EPD Rules for wood and wood-based products

The European Standard EN 16485 provides rules for Environmental Product Declarations (EPD) specifically for wood and wood-based products in the context of the suite of standards that are intended to assess the sustainability of construction works. It complements the core product category rules for all construction products and services as established in EN 15804 (product level of CEN/TC 350 “Sustainability of construction works”).

5.3 International core sustainability indicators for buildings

5.3.1 ISO 21929 and the family of International Standards

ISO 21929-1:2011 follows the principles set out in ISO 15392 and, where appropriate, is intended for use in conjunction with, and following the principles set out in, ISO 26000, ISO 14040 and the family of International Standards that include ISO 14020, ISO 14021, ISO 14024 and ISO 14025. Where deviation occurs or where more specific requirements are stated, ISO 21929-1:2011 takes precedence.

ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements

ISO 14041, ISO 14042, ISO 14043 have been revised by: ISO 14040:2006

ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

5.3.2 ISO 21929-1:2011 core sustainability indicators

ISO 21929-1:2011 Sustainability in building construction - Sustainability indicators - Part 1.
ISO 21929-1:2011 establishes a core set of indicators to take into account in the use and development of sustainability indicators for assessing the sustainability performance of new or existing buildings, related to their design, construction, operation, maintenance, refurbishment and end of life. The core set of indicators provides measures to express the contribution of a building to sustainable development. These indicators represent aspects of buildings that impact on areas of protection related to sustainability.

ISO 21929-1:2011 adapts general sustainability principles for buildings; includes a framework for developing sustainability indicators for use in the assessment of economic, environmental and social impacts of buildings.

In the list of core indicators from ISO 21929 the indicators for “Global warming potential” and “Ozone depletion potential” are compulsory Life Cycle Impact Assessment indicators. The indicator “Life Cycle Costs” is introduced at least on the level of planning.

Number	ISO 21929-1:2011 Core Sustainability Indicator	Object of assessment
1	Global warming potential	Building
	Ozone depletion potential	
2	Amount of non-renewable resources consumption by type (natural raw materials and non-renewable energy)	Building
3	Amount of fresh water consumption	Building
4	Amount of waste generation by type (hazardous and non-hazardous wastes)	Building
5	Change of land use *assessed with help of criteria*	Site
6	Access to services by type *assessed with help of criteria:*	Location
	public modes of transportation	
	personal modes of transportation	
	green and open areas	
	user-relevant basic services	
7	Accessibility *assessed with help of criteria:*	
	accessibility of the building site (curtilage)	Site
	accessibility of the building	Building
8	Indoor conditions and air quality *assessed with help of criteria:*	Building
	indoor thermal conditions	
	indoor visual conditions	
	indoor acoustic conditions	
	indoor air quality	
9	Adaptability *assessed with help of criteria:*	Building
	change of use or user needs	
	adaptability for climate change	
10	Life cycle costs	Building
11	Maintainability *assessed with help of criteria*	Building
12	Safety *assessed with help of criteria*	Building
	structural stability	
	fire safety	
	safety in use	
13	Serviceability *assessed with help of criteria*	Building
14	Aesthetic quality *assessed with help of criteria*	Building

Table 5-1 Core sustainability indicators of ISO 21929-1:2011 (Lutzkendorf)

5.4 Glossary

Refurbishment
The remodelling, refashioning and general renovation of a building, site, product or infrastructure.

Giving outdated buildings a new purpose with an upgrading and reconfiguration that goes beyond the cosmetic.

Extending the useful life of existing buildings through the adaptation of their basic forms to provide a new or updated version of the original structure.

Gaining cost and embodied CO2 savings. Offer operational CO2 savings too as the heating and air-conditioning requirements of the refurbished buildings are reduced.

Retrofit
The addition of energy efficiency equipment.

Retrofitting refers to the addition of new technology or features to older systems.

Deep energy retrofit / performance retrofit: retrofits that ensure maintenance and preservation of buildings and continued operation and maintenance of energy efficiency technologies.

Renovation
(Also called remodelling) is the process of improving a structure: “To restore to an earlier condition, as by repairing or remodelling.”