smartTES

Innovation in timber construction for the modernisation of the building envelope

smartTES – Introduction to a new retrofit method

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Content

1 SMARTTES  2
  1.1 Opportunities in building modernization  3
  1.2 Holistic design  5
  1.3 Added value of industrialised refurbishment  6
  1.4 smartTES - proven practice  8

2 RESEARCH PROJECT SMARTTES  11
  2.1 Method and result  12

3 SMARTTES RESULT  15
  3.1 Book 1 - Innovation and marketing  15
  3.2 Book 2 – TES extensions  16
  3.3 Book 3 - Multifunctional TES  18
  3.4 Book 4 – Building physics  20
  3.5 Book 5 – Fire safety  22
  3.6 Book 6 – TES sustainability  25

Figure List  28
List of Tables  28
Abbreviations, Units  28
smartTES – Introduction to a new retrofit method

Finding solutions for building refurbishment using prefabricated timber elements has been the task of the two research projects TES EnergyFacade and smartTES since 2007 in a European network with academic as well as industry partners from Finland, Germany and Norway.

This documentation is an approach towards the topic of industrialized prefabricated refurbishment based on modern timber construction and guides the reader through the comprehensive result of smartTES laid down in six separate books. These are structured as a compendium of general research work, highlighted with useful information pinpointed in each chapter. The books may be used separately or as a complete series.

Dipl.-Ing. Frank Lattke, project coordinator
1 smartTES

TES EnergyFacade stands for ‘timber based element system [TES] for improving energy efficiency of the building envelope’. It is a method for the application of prefabricated timber elements offering solutions for the energy efficient building envelope refurbishment as well as building extensions.

TES EnergyFacade (2008-2010) and in continuation smartTES¹ (2010-2013) have been European research projects funded under the umbrella of WoodWisdom-Net. The main goal was to open up the renovation market by building on the competences of modern timber construction methods and thus gain market shares for the Forest Based Sector.

TES EnergyFacade provides a structured guideline for the application of prefabricated large-sized timber frame façade elements along the workflow from planning, digital measurement, off-site production and on-site assembly.

Figure 1 - Building modernization as part of the wood value chain

In addition smartTES offers solutions for design, technical and ecological issues based on a further development and experiences made in demonstration projects. Main focus was on fire safety strategies, integrated building services in façade elements, robustness towards building physics as well various application of TES EnergyFacade as envelope and building extension.

The following report explains the approach of smartTES and gives an overview of the results put into six books on smartTES:

- Book 1 Innovation and marketing
- Book 2 TES extensions
- Book 3 Multifunctional TES
- Book 4 Building physics
- Book 5 Fire safety
- Book 6 TES sustainability

¹ Further information on the project can be found on www.tesenergyfacade.com
1.1 Opportunities in building modernization

We are facing an extensive need for refurbishment of the existing building stock as well as urban renewal of large areas simply to the fact, that a time frame in the life span of building materials and elements has been reached. Thus the demand for replicable modernization solutions in Europe is growing. A majority of the buildings represent the Post World War II reconstruction – era and are typically situated in suburbs, consisting of a homogenous building stock and thus forming a monotonous urban pattern. The buildings themselves are in need of extensive interventions including facades and building services at the end of their lifespan. The growing momentum of refurbishment activity gives the chance to adapt the existing buildings to current demands and future needs, for example by changing floor plans or the densification of urban patterns through building extensions.

The theme of urban mining and reuse of buildings is on the top of public discussions: the German Pavilion of the 13th International Architecture Exhibition La Biennale di Venezia in 2012 stood under the concept Reduce Reuse Recycle → Architecture as a Resource and underlined the importance of the existing building stock as energy, cultural, social and architectural resource which plays a significant role in shaping our future and adopting of a fundamentally positive attitude towards the architecture that already exists².

2nd chance for architecture

Residential areas from the 1950’s to the 1980’s often need technical, architectural and social improvement. A great number of multiple dwelling units from this time throughout Europe have reached a point where renovation within the next decade is necessary due to natural decay.

Holistic building modernization including envelope, technical services and even the adaption of floor space to today’s requirements is one of the major tasks of the present architecture and construction industries. Most challenging are large-volume buildings, e.g. schools, offices or residential buildings, which must be refurbished in an inhabited state due to missing provisional space for the users in the construction period. From the residents point of view a reduced building time on-site implemented fast and precise with less disturbance and the benefits of improved living comfort is a desirable effect.

Regarding the demand of housing and living, durable, economic and ecological solutions are necessary to transform our buildings to meet future-oriented standards regarding energy efficiency, CO2 neutrality and contemporary floor space plans. An improved insulation and air tightness level of the building envelope is a major benefit to the saving potentials of the energy consumption of a building and a vital contribution to the reduction of global CO2 emissions, along with increasing the value of our building stock.

Building modernization as a holistic intervention offers a 2nd chance for architecture and an option for urban renewal, including infill development if we succeed to implement solutions with a balanced economic, social, ecological and cultural focus.

Figure 2 - Holistic building modernization from design to assembly

² http://www.reduce-reuse-recycle.de/index_en.html (19.05.2014)
Global energy goals as background of refurbishment
A common target for the European Union is the striving for a sustainable growth and future, including the 2020 – targets for a climate friendly development. Buildings are responsible for 40% of energy consumption and 36% of EU CO₂ emissions. It is estimated that, by strengthening the provisions of the Directive on energy performance, the EU could achieve a reduction in its greenhouse gas emissions equivalent to 70% of the current EU Kyoto target. In addition to this, these improvements could save citizens around 300€ per annum per household in their energy bills, while boosting the construction and building renovation industry in Europe.

The urge to face the consequences of the climate change through eco- and energy efficient building methods has been underlined by the publication of the fourth assessment report by the IPCC and the European Directive on the energy performance of buildings. The chosen strategy is to build even more energy efficient new buildings, to a level Near to Zero Energy, and aim at cost and energy efficient improvement and refurbishment of existing buildings.

Reduction goals for the primary energy demand in 2020 and 2050 will bring long-term effects on greenhouse gas emissions aiming at achieving the climate protection goals. Building modernization offers the chance to rethink strategies of a general energy balance. Taking into account the amount of embodied energy of the existing structure as part of a total calculation, this puts demolition and reconstruction into a different light. A deep retrofit is thus often a more ecological and energy efficient solution. smartTES book 6 - TES sustainability discusses in more detail the emissions and environmental impacts associated with the refurbishment of the existing building stock. There is a temporal divergence between the construction and user phase impacts that should be considered in decision making on the retrofit method.

Furthermore the construction sector accounts for over half of the yearly amount of waste produced by our society. Reducing waste means to reduce resources needed to produce construction material. The idea is to save by spoiling less. The timber construction sector is characterized by prefabrication in workshop environments focusing on resource efficiency as construction materials are customized, ordered and cut accordingly, thus producing less losses and waste.

The role of wood as a building material
European as well as national action plans have formulated ambitious targets to tackle global climate change in the near future. Buildings alone are responsible for 36 % of EU CO₂ emissions deriving from both building materials and energy consumption.

In this context, an increased use of renewable, carbon efficient resources and products in the construction sector plays a significant role. By building with wood we can increase the amount of embodied carbon dioxide. Wood has a promising potential to provide a positive energy and carbon balance over the whole lifecycle, from the forest to wood products including the end of life. Additionally, as long as the material is harvested from sustainably managed forests, timber is an environmental friendly choice of building material.

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3 Intergovernmental Panel on Climate Change
4 EPBD 2002/91/EC
5 LUX, Intelligente Energie, page 18-19, Oktober 2013
6 Wegener G., Bauen mit Holz = aktiver Klimaschutz, Holzforschung München WZW, 2010
1.2 Holistic design

The TES – method allows for a complete regeneration of existing buildings. The role of the architect is hence highlighted. However, when aiming for a comprehensive refurbishment and demanding targets for energy efficiency, the importance of a friction free workflow and design team is enhanced.

Holistic design and planning in a team of architects, engineers and other experts is a process of decision making already at an early project stage. The structured workflow of TES EnergyFacade provides the necessary framework by activating a strong momentum in a design and construction process.

A thorough design phase is necessary to fully comprehend the scope of a refurbishment project, elaborate on the goals and set targets with respect to architecture, technical requirements (e.g. structure, building physics), budget and schedule. The design phase offers freedom to develop complete solutions and test different options to best match set requirements. Decision making on-site is more of a reaction plan to single situations with an uncertain economic effect. Moreover, late changes during the building process often cause higher cost at the end as decisions taken in an early project stage have to be amended. Especially changes to construction elements in production or even on-site are expensive.

A comprehensive and accurate building analysis is essential in the early planning stage. A thorough recording of the building is recommended as to identify its structural and physical weaknesses, the requirements of building codes, fire protection issues, technical equipment and user needs. The evolution of refurbishment solutions will be more successful if the information collected and evaluated in the beginning of the process is complete.

A stepwise planning and procurement process has so far proven realistic and feasible. Architectural design on the basis of existing plans and / or a rough survey as a set of 2D drawings has proven a sufficient basis for tendering and production planning of the following contractors. Carpenters use similar CAD software tools for production planning. Hence the process is well established on the basis of the experience of carpentry for new buildings.

Regarding building modernization using prefabricated timber element systems (TES), basic design recommendations along the workflow chain from building survey, design, production planning and assembly have been documented in the TESmanual, the official project report of TES EnergyFacade. In addition, smartTES has set the scope for advancing technical issues such as fire safety and building physics, building extensions as well as marketing strategies.

Figure 3 - Ratio of time and cost during the planning and construction process

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1.3 Added value of industrialised refurbishment

Contemporary timber construction is characterized by standardized planning and construction processes based on a high level of prefabrication. This offers great opportunities for building modernization. Using large sized prefabricated elements is a premise for economic and fast construction processes. However, it requires increased efforts in the planning phase, during which the elements, their transport logistics and assembly are designed on the basis of a thorough building analysis. The use of prefabricated construction elements improves the productivity during the on-site assembly and leads to less disruptions of operations and less disturbances of the living environment.

Today, the production of wall and roof elements or spatial modules with a high level of prefabrication is state of the art in timber construction. Rationality and precision determine the manufacturing process. Standardized, optimized and monitored processes from the inventory management to the production allow for a high standard of quality.

![Figure 4 - production off-site, workshop environment](image)

One of the big advantages of prefabrication is the rational production of components based on a controlled workflow in the workshop under constant conditions. Building materials are used more efficiently and less waste is caused in the process. Machines, e.g. digital joinery machines and assembly tables, increase the precision and rationality of the production. Controlled conditions enable the production of complete and highly precise timber based elements, with a core of, for example, either a load bearing frame structure or cross laminated timber (CLT) and possibly with integrated components like windows and a finished cladding layer. Production quality standards secure an accurate execution and ensure e.g. the airtight level or the protection of finished surfaces. The regular size of timber framed elements is dependent of the dimension of production machines, transport and lifting facilities.

**TES EnergyFacade on site**

Construction work on a building site is traditionally characterized by in-situ operations, handling of building materials in small items piece by piece. The process can be lengthy and inefficient, which requires a high degree of discipline of all those involved and effort for the coordination of individual works. Experience with prefabricated systems proves, the more decisions and production
processes can be conducted off-site beforehand, the easier and faster the construction process works.

TES EnergyFacade elements have a self-supporting structure. Transport and lifting techniques allow for a very precise handling of the finished elements during the manufacturing and assembly process (Figure 5). The spatial situation of the site affects transport and assembly logistics. The degree of prefabrication and the alignment of the façade panels are dependent of the geometry of the building. Possible crane locations are chosen in relation to the accessibility, the dimensions and the weight of the elements. Safety of all participants is a supreme premise during the entire construction phase.

![Figure 5 – Mounting of elements, Photo Stefan Thessenvitz](image)

Peter-Schweizer-Schule, Gundelfingen, Germany (Thessenvitz) The façade was produced of 7.96 meter high TES elements over two stories, mounted without any significant damage to the color-coated fiber cement panels.

**smartTES main characteristic**

<table>
<thead>
<tr>
<th>Construction</th>
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</thead>
<tbody>
<tr>
<td>• Self load bearing timber frame construction with insulation and paneling</td>
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<tr>
<td>• Design freedom with a great variety of cladding materials (e.g. timber panels, sawn boards, metal sheet, glass etc.).</td>
</tr>
<tr>
<td>• Precision and quality of prefabrication</td>
</tr>
<tr>
<td>• Extension with space modules based on timber construction</td>
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<tr>
<td>• Integration of building services and/or solar-active components</td>
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<tr>
<td>• Integration of structural components such as a balcony platform</td>
</tr>
<tr>
<td>• Optimization of building works on site</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Values</th>
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</thead>
<tbody>
<tr>
<td>• Architectural renewal</td>
</tr>
<tr>
<td>• Improvement of the energetic performance and the comfort of a building</td>
</tr>
<tr>
<td>• Use of renewable raw materials for the building modernization</td>
</tr>
<tr>
<td>• Optimization of productivity on site</td>
</tr>
<tr>
<td>• Short construction time = less dirt and noise on site</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Knowledge</th>
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</thead>
<tbody>
<tr>
<td>• Digital measuring method, reverse engineering</td>
</tr>
<tr>
<td>• A systemized workflow based on an integrated planning process, supported by BIM in design, construction and maintenance procedures</td>
</tr>
</tbody>
</table>

Table 1 – smartTES - main characteristics
1.4 smartTES - proven practice

By 2014, nine building refurbishments have been realized using TES Energy Façade within the framework of multi-scientific, international research\(^8\) and development projects. smartTES was thus able to gain insights for the application, evaluation and monitoring of proposed technologies and processes. Some of the research partners were contracted for planning and construction work, achieving a significant balance between research and practice. Realized demonstrations are situated in different European locations with the southernmost located in the surroundings of Munich in Germany and the most northern one in Oulu, Finland. The pilots represent residential, office and school buildings with the oldest ones originating from the 1960’s and the youngest deriving from the mid 1980’s. The largest object is the retrofit and refurbishment of the tax offices in Oslo Norway – a building of up to 11 stories and 40,000 m² of façade retrofitted with prefabricated TES elements. The TES façade elements have either replaced the old façade completely or partially or the retrofit has been realized by assembling the new façade elements directly onto the existing wall. All projects include significant additions of thermal insulation aiming at energy efficiency levels of passive house or low energy demand (local definitions) and showcase a complete architectural regeneration of the building facades.

Lessons learnt

<table>
<thead>
<tr>
<th>Architecture</th>
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<tbody>
<tr>
<td>Building retrofit is much more than additional insulation, new windows or technical components. Building modernization offers the chance to advance the existing substance in design, barrier free and social issues to upgrade buildings for future needs. Monitoring results and tenant questionnaires clearly underline the acceptance of added values.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement and tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>The non-contact measurement methods (3D laser scan, tachymetry) are offered by professional engineers for surveying or can easily be performed with the necessary device by construction companies as part of the service. The most important preparation is the definition of all measuring points on the building and a common interpretation of the results in the planning team. The wall elements produced after the measurement can be mounted precisely on the buildings, presumed that the elements are positioned carefully.</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Planning</th>
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<tbody>
<tr>
<td>A comprehensive and accurate building analysis is a vital part in the early planning stage. A thorough investigation of structure and materials used as well as documentation of the actual state of the building is recommended to identify the weakness, requirements of building codes, fire protection, structural use and technical equipment as a basis for a coordinated action plan.</td>
</tr>
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<table>
<thead>
<tr>
<th>Assembly</th>
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<tbody>
<tr>
<td>The spatial situation of the site affects transport and assembly logistics. The degree of prefabrication and the alignment of the façade panels are dependent on the geometry of the building. Possible crane locations are chosen in relation to the accessibility, the dimensions and the weight of the elements. Safety of all participants is supreme premise during the entire construction phase.</td>
</tr>
</tbody>
</table>

\(^8\) TES EnergyFacade (2008-2010), smartTES (2010-2013), E2ReBuild (2011-2014)
Finland

Concurrent with the smartTES project one TES pilot project was realized in Oulu, northern Finland. The planning process started in 2011 and the building modernization was realized in 2012-2013.

The object is a 2-storey high residential building hosting social student housing. The aim for the refurbishment was to test and evaluate the replication potential of TES elements for façade retrofits, to upgrade the building energy efficiency close to passive house level suggested local standard and to rebuild the apartments as to meet requirements of modern student families.

Structurally the building, even if originating from the mid 1980’s, represents the BES system – a concrete building standard developed in Finland in the late 1960’s. The BES system is based on the use of load bearing concrete walls and non-load bearing, prefabricated concrete sandwich façade elements. In early implementations the load bearing frame was built on site but over time the system developed into a holistic, industrialized approach with a fully element based structure and predesigned details. Today, every fifth Finnish apartment is located in a concrete apartment building from the late 1960’s or early 1970’s and forms the replication potential for proven refurbishment concepts for these buildings.

The building at Virkakatu in Oulu was retrofitted using prefabricated TES elements for the building facades and elements for the roof built on site. The airtightness of the old inner concrete layer was improved prior to element assembly. New building services were installed including apartment wise mechanical ventilation units with efficient heat recovery. The passive house certificate for refurbished buildings is under consideration. The environmental footprint of the process is evaluated in smartTES book 6 - TES sustainability.

Figure 6 - Finland Virkakatu 8, Oulu. photo left: Simon le Roux, Aalto University. photo right: Jaakko Kallio-Koski M3 Architects. Façade retrofit and holistic refurbishment realized in 2012-2013. Left image shows the building during demolition phase. The outer layer of the concrete sandwich elements were removed prior to the assembly of new TES elements. The right image shows the finalized building. The façade material is cement fiber board. Demonstration part of project E2ReBuild9

9 www.e2rebuild.eu (21.05.2014)
Germany
In Germany the TES EnergyFacade has been applied to several buildings of different functional types such as schools and residential buildings. Experience has been made applying elements to load bearing brick walls as well as non-load bearing concrete element or steel glazing facades.
The projects demonstrate the added value design and technical aspect. The vision of the retrofit project in Augsburg, Grüntenstrasse was to transform the old building into a contemporary piece of architecture. The wrap around solution of the TES façade was cladded with rough sawn, white painted spruce boards. The new design supports the visibility of the building in the urban context. The existing balconies were converted into winter-gardens or living room extensions thus offering extra interior living space and additional balconies offer outdoor space. With these measures, additional value was created, which leads to higher acceptance of the whole modernization of the block. The TES method has proven successful for the refurbishment in an inhabited status. In Augsburg, envelope, access as well as bathrooms were retrofitted with tenants staying in their apartments.

Norway
The process of renovating facades with TES-elements is new in Norway, the facades were very large and there were solutions in the facade system that was controversial compared to traditional Norwegian building traditions. The renovation of the facade demanded focus on several different issues compared with on-site construction work.
The retrofitting of Fredrik Selmersvei 4 in Oslo includes upgrading the energy efficiency to Energy Class A and passive house level. The new facade is TES-elements produced by former Trebyggeri AS, with integrated low energy windows. A recirculated aluminum cladding is mounted on the TES elements on site. The building is one of the largest office buildings in Norway, and is owned by the public company Entra Eiendom. The office was built in 1982 and consists of five blocks with 7-11 floors. The building used to have a brick cladding combined with aluminum sheets before renovation. Due to large thermal bridges in the facades it was decided to remove the original facades and keep the loadbearing concrete skeleton structure The original available area was 32
000 m², but was expanded with 4 000 m² after the renovation. The expansion is performed by including areas between the blocks into the building.

Figure 8 - Fredrik Selmersvei 4 in Oslo. photo: invisio

During retrofit and finalized project. This is one of the first retrofitted office buildings in Norway to achieve such low energy demands. One part of the renovation process was to replace the facade, plus expand the building by making some changes to the volume of the building which also increased the compactness.

2 Research Project smartTES

The main objective of smartTES was to advance the method of energy efficient building modernisation with large-scale prefabricated timber elements based on the results of TES EnergyFacade (1). Following aspects were further developed on the way to introduce a marketable result of the building system:

- **smart TES** - development of a ‘value-added facade’ as a multi-functional building envelope including a robust low tech and economic solution for an energy producing façade (air collector façade, thermal collectors, PV panels)
- Systemization of interfaces (“plug and play”) and integration of technical components, (e.g. HVAC devices, ducts, vents, ITC infrastructure, electro-installation) and development of model solutions. This includes mock-ups, testing and monitoring of properties and behaviour.
- **TES extension** – investigation and systemisation of legal and technical requirements for the retrofitting of pitched and flat roofs and/or additional storeys and extensions as a densification strategy in the urban context.
- Development of a coherent timber construction system for additional storeys and building extensions compatible with TES EnergyFacade
- **TES in an urban context** – validation and documentation of the value of TES in urban infill developments and its architectural possibilities
- Certification of environmental footprint and LCA for basic solutions and demonstration projects
- Understanding the building and building modernisation as a holistic system of building envelope, building services, technologies, climate, energy, architecture and end user
- Climate adaption of prefabricated low energy building envelope technology
- Monitoring and testing of mock-ups and demonstration projects to gain a necessary basis of information for the development and standardisation of basic solutions
• Speed-up the process from production to assembly in order to create a holistic industrialised process that aims to minimise disturbance for tenants and facilitates energy efficient operation and use of buildings.
• Dissemination – bringing results from research to business

### Table 3 – Synopsis of research projects TES EnergyFaçade and smartTES

<table>
<thead>
<tr>
<th>TES EnergyFaçade</th>
<th>smartTES</th>
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<tbody>
<tr>
<td><strong>Key results</strong></td>
<td><strong>Key topics</strong></td>
</tr>
<tr>
<td>• Digital workflow based on digital survey</td>
<td>• Multifunctional solutions for wall elements and space modules</td>
</tr>
<tr>
<td>• Systemisation of requirements</td>
<td>• Environmental assessment</td>
</tr>
<tr>
<td>• Definition of a basic construction system with detail catalogue</td>
<td>• Product resource efficiency</td>
</tr>
<tr>
<td></td>
<td>• Sustainability of application in the modernisation process</td>
</tr>
<tr>
<td></td>
<td>• TES in urban context</td>
</tr>
<tr>
<td></td>
<td>• Measures to speed up the modernisation process</td>
</tr>
<tr>
<td></td>
<td>• Demonstration projects, monitoring</td>
</tr>
<tr>
<td><strong>Important milestones</strong></td>
<td><strong>Important milestones</strong></td>
</tr>
<tr>
<td>• Demonstration projects (Risør College, Realschule Buchloe)</td>
<td>• Revised detail catalogue including building services</td>
</tr>
<tr>
<td></td>
<td>• Demonstration projects</td>
</tr>
</tbody>
</table>

2.1 Method and result

**smartTES** research project was divided into 8 work packages grouped according the main overall topics construction, implementation, dissemination and validation. The results were developed in following work packages and tasks:

1 – **Multifunctional TES**
T 1.1 Production: Integrated energy supply systems (passive - active)
T 1.2 Distribution: Integration HVAC, plumbing, IT and building services
T 1.3 Use: Passive heated building envelope
T 1.4 Windows
T 1.5 Fire safety

2 - **TES extension**
T 2.1 Investigation: case studies, experiences of realized projects
T 2.2 Systemisation of requirements
T 2.3 Design and implementation of a basic construction system
T 2.4 Model solutions for annexes and extensions

3 - **TES urban renewal – Social aspects of building modernisation**
T 3.1 Technical Scenarios
T 3.2 Meeting residents needs
T 3.3 Best practice

4 - **TES market access**
T 4.1 Process development “Speed up the process towards an industrial level”
T 4.2 Market needs
T 4.3 Market concept

5 - **TES sustainability**
T 5.1 Criteria’s and guidelines for sustainability
T 5.2 Integrated modernisation
T 5.3 Material flows (LCA, improvement of the whole product quality)
6 - Climate adaption of buildings
T 6.1 Criteria's and guidelines for low energy design
T 6.2 Detailed building physics studies of construction details/smartTES
T 6.3 Climate adaption of smartTES Buildings in cold and wet climate
T 6.4 Monitoring of built projects

7 - Dissemination
T 7.1 Experts Panel
T 7.2 Communication
T 7.3 Best practice

8 – Coordination
T 8.1 Project management

Project and working method
The project smartTES brought together different partners working in the fields of energy efficient building design, timber engineering and construction and building services with different experience and knowledge of building in different climate regions throughout Europe. The participants were willing to contribute to this transnational cooperation sharing expertise, synergies and cooperative research activities.

The project offered the possibility to share knowledge and bundle capacities from research organisations as well as small enterprises in order to further develop a European marketable and standardised timber building system to face the challenges of CO2-reduction of building consumption.

The TES method is a systemised retrofitting process of surveying, planning, construction and maintenance of the building stock.

The main objective of the project was to optimise this process with a strong focus on the development of practicable solutions.

Necessary responsibilities of all participants were set within the particular competences along the digital workflow from survey, planning, integration and production.

Figure 9 - Project Management and process chain
Along this process chain, solutions for missing links were developed in a joint team effort. The scientific approach met with the pragmatic working culture of the participating business partners. The specific task was dissected; a team of architects, engineers and timber contractors designed the solution and tested its practicability. The SME partners are motivated to contribute with money, resources and knowledge to develop cutting edge solutions in a limited time frame as they value the benefit to gain advantage through applied re-search.

The result of smartTES is documented in six books covering all important aspects of refurbishment with prefabricated timber elements:

- Innovation and marketing
- TES extensions
- Multifunctional TES
- Building physics
- Fire safety
- TES sustainability
3 smartTES result

3.1 Book 1 - Innovation and marketing
Authors: Anja Thessenvitz M.A., Stefan Thessenvitz

The business model “Science to Crafts” is the frame story for the market entrance of smartTES. The partners are well experienced in courses, lectures and seminars; the dissemination of knowledge is established and can be easily focused and expanded. The future work of the smartTES partners concentrates on the implementation and ensuring of the smartTES Creation-of-Values “Costs – Time – Precision” from the marketing point of view. This will lead to the main arguments for the stakeholder to choose the sustainable smartTES-system.

The core teams are defined to bring “Science to Crafts” into action in Norway, Finland and Germany. A specific mission for each country has been worked out:

Mission smartTES Norway “Science to Crafts”

smartTES Norway stands for applied research and development for the building sector. The core is knowledge transfer. smartTES Norway develops knowledge and provides technical approvals to actors in the building sector.

Mission smartTES Finland “Science to Crafts”

smartTES Finland stands for a network of Research and Technological Development (RTD) and for the organization in association with the wood industry partners. smartTES Finland promotes research, development and dissemination work for the scientific community and public interest groups. SmartTES
Finland offers excellence in scientific exchange, education and sharing of the state of art experiences\textsuperscript{10}.

**Mission smartTES Germany “Science to Crafts”**

smartTES Germany stands for development of new ideas, methodical structuring, solution work out and general solutions (like windows). smartTES Germany make proposals for standardization and requirements and independent investigations on facts for the general public. The university’s neutrality of smartTES Germany is a connection between the planning offices and the manufacturers.

To clients and partners smartTES Germany promises

- Direct implementation and usefulness of the results from the executing timber manufacturers, architects and engineers
- Publication of best practice solutions (proven by a certain process of evaluation within the research project)
- Definition and identification of risks
- Proof, that it works Assertion : proof building trust

### 3.2 Book 2 – TES extensions

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Kai Nordberg, Aalto University School of Engineering, Department of Civil and Structural Engineering

Wolfgang Huß, Technische Universität München, Chair for Timber Architecture

The scope of the research was to develop model solutions for timber based building extensions that can be accomplished in connection to a TES Facade renovation. The aim was to find solutions for structural timber-based systems for rooftop and horizontal extensions.

The research focuses on creating exemplary solutions from architectural, structural and building service system’s point of view which fit to the most typical suburban buildings (i.e. concrete element apartment buildings built in the 1960's and the 1970's in Finland or concrete brick buildings from the 1950's post-war era in Germany). The solutions are also designed to meet current energy efficiency requirements for new buildings. The TES Extension process is designed to be compatible and executed in connection to a TES Facade renovation or as an independent extension.

TES Extension solutions follow the principle that tenants in the old, existing building have the possibility to continue living in their apartments during the whole renovation process. TES Extensions can be realized as prefabricated space modules even with integrated building service systems. This shortens the work on site and provides a high level of finishing including final surface materials with the pre-installed building service systems. Using prefabricated space modules shortens significantly the work on site where only assembly takes place, hence reducing the disturbances to the tenants.

\textsuperscript{10} The group has supported the E2ReBuild demonstration in Oulu by helping to facilitate the communication of decision making during the design and construction process.
The book contains examples of state-of-art / best practice projects, a review of the existing building stock, definitions of requirements for extensions and model solutions for case-study buildings.

This research is the first step defining the possibilities of TES based rooftop extensions. The examples are presented as generic concepts based on high standard prefabricated space modules which provide fast and tenant friendly options for vertical or horizontal extensions for the existing building. Easy maintenance is another important aspect of the concept. The extension space modules are designed and constructed so that certain building components are easy to maintain or even replaced when needed. This creates added values to the solution over time reducing the lifecycle maintenance costs.

The transportation limits and locally available crane capacity also plays a significant role in the planning of space modules for extensions. There are also local legislation differences that need to be taken into account in different European countries. Usually special transport methods are required for the delivery of the space modules and the optimum module dimensions should be investigated separately for each case. Also the availability of the crane capacity is dependent on the location, as moving special cranes can be costly.

As a result of the Finnish case study for vertical rooftop extensions on top of typical concrete apartment buildings, it can be concluded that a rooftop extension is most convenient solved using a “smart” adjustment structure between the existing building and new rooftop floors. The prefabricated “smart” adjustment layer has multiple functions. It has a structural purpose dividing the loads of additional floors to the load bearing walls of the existing building and the adjustment layer also evens the irregularities that are likely to exist between the existing building and extension, hence allowing tolerance for the prefabricated housing modules. Thirdly the adjustment layer provides space for rerouting the required ductwork systems, making the layout of the extension floors more flexible.

It is worth to notice that different solutions are needed, based on the properties and suitability for extensions of the old building. The suitability of the existing building for the extensions needs to be studied case-by-case, as the structural suitability of the existing building defines both the limitations as well as possible solutions. More detailed construction specific solutions require further investigation in future researches.

Loggias have a high degree of wall surface towards the heated room thus layering additional insulation thermal bridge free leads to complication of details as well as reducing space. Adding extra space in form of a space module as shown in the images, creates a significant architectural added value. Image shows retrofit of Schlägerstraße, Hannover, Germany, lattkearchitekten.
3.3 Book 3 - Multifunctional TES
Authors: Stephan Ott, Stefan Loebus, TUM Technische Universität München
Chair of Timber Structures and Building Construction
Berit Time, SINTEF Building and Infrastructure, Trondheim, Norway
Anders Homb, NTNU (Norwegian University Of Science And Technology)
Trondheim, Norway
Rafael Botsch, University of Applied Sciences Rosenheim, Rosenheim, Germany

The book describes general principles for the integration of building services into the building envelope. Especially ventilation as an additional feature is required in airtight buildings after renovation. smartTES has investigated in ways of how to integrate duct work into TES façade elements as an option to interior installations. TES is equally suitable for the integration of various innovative concepts. These are examined for their applicability and integration capability in TES elements. This involves the integration of active components in elements, the connection of building services via TES elements with central devices, and reactive building envelopes as a holistic energy absorber. These solutions must be integrated as a whole system, not only to the TES element but also in the existing building.

Ventilation
Existing buildings demonstrate complex situations when retrofitting ventilation systems. It is more difficult for building services concepts to react on the as-built situation compared to new building, where it is designed in a collaborative way. With building service systems integrated in the envelope there is a higher flexibility in the development of well adapted solutions.

Starting with a general comparison of national standards in Finland, Germany and Norway different ventilation concepts are described and an overview about the complex topic of fresh air supply and ventilation in existing dwellings is given. Focusing on heating, ventilation and air conditioning (HVAC) concepts which can be used in TES-integrated or in TES-connected elements are demonstrated. Available concept and technical devices on the market or recent developments are highlighted. New developed concepts and systems for smartTES multifunctional envelopes are shown in the subsequent chapter.

Figure 11 - Principles of a TES-integrated (left), TES-connected (middle), TES-envelope concepts, technical installations in the building envelope.
Installation of an HVAC system in an existing building may be solved in different ways. It will of course depend very much on the type of building and if one or more vertical shafts are available in the existing building. For these buildings, small to medium vertical shafts normally exist, usable for at least the outlet air of a modernized HVAC system. The smartTES element offers space for installing pipes for, for instance the inlet air. The report presents three possible installation scenarios (individual, one installation per staircase or central unit per building) with a further evaluation based on a new HVAC system.

Holistic concepts for the multifunctional building envelope must be adapted to the particular case in detail. The necessary preliminary studies and the planning process are complex, since additional constraints, as compared to basic façade renovation, are taken into account. The constraints include the building in its specific situation, existing systems, alternative new systems and service life of the components as well as sustainability of the entire concept. All these parameters define the scope and depth of the intervention to be made in the existing substance and the related technologies and risks. Collaborative planning is the essential prerequisite to minimize risks and to ensure success. Further planning recommendations are given.

Passive heated building envelope (PHBE)
In smartTES the envelope concept of a passive heated building envelope (PHBE) is part of this research report. It is a new development of a responsive envelope and a result of the cooperation of the companies B&O Wohnungswirtschaft, Huber&Sohn and the University of Applied Sciences Rosenheim. The reverse flow of a solar thermal plant is used to heat up the exterior walls of a building. This is done by using thin heating pipes integrated to the back side of TES-facade elements, behind the insulation layer. The approach is the reduction of the heating demand by lowering the effective U-value of the regarded façade. By heating up the PHBE, transmission losses (Qe) through the external wall are reduced to a minimum. Depending on the thermal input to the PHBE, transmission losses can even be converted to energy gains (Qi).
The model of the passive heated building envelope has run through several tests to evaluate following aspects:

- Air-tightness of the attached TES-element to the façade
- Thermography
- Evaluation of the temperature-profile (heat transfer through the entire façade)
- Sound and moisture proofing

The results have not fully supported the main approach to use solar gains and rest energy of a solar heating system to improve the performance of the building envelope. Nevertheless a comprehensive documentation allows insights into a promising idea.

3.4 Book 4 – Building physics

Authors: Anders Homb, Berit Time, Lars Gullbrekken, Magnus Vågen, Silje Korsnes, Holger Halstedt, SINTEF Byggforsk | SINTEF Building and Infrastructure
Stig Geving, NTNU University Trondheim
Juha Päättalo, Kimmo Lylykangas, Aalto University School of Arts, Design and Architecture, Department of Architecture

Correctly planned and executed details to fulfill the requirements of building physics are a precondition for robust performance of timber elements for wall and roof structures. smartTES investigated a procedure for how to deal with climate adaption in a renovation project with a TES application in different European climate regions and what is needed to be considered. Furthermore it presents findings and results from activities in this project related to climate, climate adaption measures and building physics.

The comparison made shows climate parameters important for building design for different locations in the three countries Finland, Germany and Norway. Three representative locations have been chosen in each country. The comparison shows that there are fairly large national and also transnational differ-
ences in climate zones. Building practice, traditions and codes in the different countries are reflected by the climate of the country.

In smartTES laboratory measurements have been carried out to investigate rain- and air tightness of a TES element. Three different tests of rain tightness of wall objects including a window have been carried out to investigate the vertical and horizontal joints of a wall element, wall-window interactions and mounting details of the window.

Due to an increasing interest to use OSB/3 boards (Oriented Strand Board) as water vapor retarders and/or wind barriers in TES elements and prefabricated wooden wall elements both in new and renovated buildings and in passive houses in Norway, smartTES investigated in the performance of such boards under extreme weather conditions. Laboratory testing as well as numerical calculations show that the risk of mold growth is small in the wall element.

In terms of climate adaption of a smartTES renovation it is advisable to assess the framework conditions for the exposed building envelope. The conditions of existing buildings with its present geometry, construction and materials which are under renovation differ. The renovation might be planned because a building has achieved its aesthetical, technical and/or economical limits.

The geographical location as well as the climate exposure on the site needs to be considered. The smartTES solution selected has to be adapted to the climate in situ.

A third framework condition is the energy standard of the existing building and the ambition or level of performance for the renovated building. The TES solution will differ from a national norm level to a passivhouse level.

In the following, a procedure is proposed for the assessment of climate exposure and building physical aspects in design of smartTES facades. Four main topics have to be handled in an iterative process:
### Topic | Assessment
--- | ---
**Moisture safe construction** | • Determine hygrothermal properties for the existing and the new materials in the building envelope  
• If doubt about the hygrothermal performance, assess moisture calculations

**TES-element assembly details** | • Adaption to original surfaces  
• Mounting/Fixation of elements  
• Rain-tightness of facades and joints both within and between TES-element  
• Air-tightness of joints within and between TES-elements  
• Integration of multifunctional elements (e.g HVAC, see Book 3 for solutions)

**Energy Performance** | • Define the energy requirement (i.e. according to legislation or higher standards, passivhouse level)  
• Plan smartTES façades (walls, windows and doors) in relation to the overall performance/requirement for the building  
• Document the thermal performance of the components (U-values, thermal bridges) by calculation or measurements  
• Calculate the overall energy performance of the building  
• Consider other construction aspects in to the evaluation, e.g. HVAC integration

**Quality in the building Process** | • how to ensure airtightness  
• how to ensure moisture protection during assembly and mounting phase

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### 3.5 Book 5 – Fire safety

Stefan Loebus, Norman Werther, TUM Technische Universität München  
Chair of Timber Structures and Building Construction

Kathinka Friquin, SINTEF Building and Infrastructure, Trondheim, Norway

Tomi-Samuel Tulamo, Aalto University School of Arts, Design and Architecture  
Department of Architecture

smartTES compares national requirements and provides solutions for details based on real fire tests as well as current national and European fire safety regulations. A predictable scenario in case of a critical incident concerning fire spread, safety for inhabitants and successful intervention of fire brigade forces is a major concern of the present work.

Critical junctions and the window-opening have been studied closely. Detail solutions have been developed and examined in computational simulations and real fire tests. After testing various construction details in orientating small-scale fire tests in a furnace, a full-scale fire test was performed. The test results are shown in the following. In conclusion, recommended, exemplary construction details are given.
Figure 15 - Fire testing, photo Stefan Loebus
Real fire tests of critical details such as window openings in a TES façade have been successfully performed to test and prove designed solutions.

By comparing the national requirements of Finland, Germany and Norway, the clearly different regulation systematics within Europe becomes obvious. Although the standard European classification notation (according to EN 13501) has been harmonized and implemented in all three countries, enabling a European-wide product applicability with one and the same technical approval (ETA), the field of application differs partially.

Table 1 summarizes component requirements for a TES façade as (part of) an exterior wall with either fire-separating functions only or additional load-bearing functions, and the material requirements for the cladding surface.

In Finland, buildings are categorized in three building fire classes (P1, P2 and P3). The fire classes are defined by building height, gross floor area, floor count and building occupancy. Within fire classes P1 and P2 there is further differentiation for the load bearing and fire separation requirements based on the expected fire load.

In Germany, buildings are categorized in five building classes (Gebäudeklasse 1-5). Buildings are categorized based on the height of the highest floor level, the size of their units of use (Nutzungseinheiten), type of occupancy and position next to other buildings.

In Norway, buildings are categorized in six Risk classes (Risikoklasse 1-6) and four Fire classes (Brannklasse 1-4). The Risk class is based on the threat a fire can entail in relation to danger to life and health. The Risk classes shall provide a basis for design and construction to ensure escape and rescue in case of fire. The Fire class is based on the consequences a fire can entail in relation to danger to life, health, social interests and the environment. The Fire classes shall provide a basis for design and construction to ensure the structure's load bearing capacity in case of fire. Buildings are categorized based on their utilization and number of floors. The Norwegian Technical Regulations do not quantify the fire resistance of building components, but describes the quality of it. Therefore, the fire resistances given in Table 1 are therefore not absolute requirements, but pre-qualified fire performances given by the Guideline to the
**Technical Regulations.** Materials or building components with other fire performances, for example combustible materials in load bearing or separating walls for buildings in BKL 3, can be used if documentation shows that the solution meets the requirements given in the Technical Regulations.

<table>
<thead>
<tr>
<th>Specification</th>
<th>P3 (small buildings ≤ 2 floors)</th>
<th>P2 (total height including extension ≤ 9 floors ≤ 20 m)</th>
<th>P1 (single floor rooftop extension)</th>
<th>P1 (building height ≤ 2 floors)</th>
<th>P1 (building height &gt; 3-6 floors ≤ 26 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire-Loading</td>
<td>≤ 600 ≤ 600 - 1000 ≤ 1200 ≤ 1200</td>
<td>≤ 600 only</td>
<td>≤ 600 ≤ 600 - 1000 ≤ 1200</td>
<td>≤ 600 ≤ 600 - 1000 &gt; 1200</td>
<td>≤ 600 ≤ 600 - 1200 &gt; 1200</td>
</tr>
<tr>
<td>Load bearing</td>
<td>80 120 180 80</td>
<td>80 80 80 80</td>
<td>80 80 80 80</td>
<td>80 80 80 80</td>
<td>80 80 80 80</td>
</tr>
<tr>
<td>B-1 0</td>
<td>B-1 0</td>
<td>B-1 0</td>
<td>B-1 0</td>
<td>B-1 0</td>
<td>B-1 0</td>
</tr>
<tr>
<td>Cladding</td>
<td>B-s2, d2</td>
<td>B-s2, d2</td>
<td>B-s1, d0</td>
<td>B-s1, d0</td>
<td>B-s1, d0</td>
</tr>
<tr>
<td>Fire- Separating</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Load bearing</td>
<td>-</td>
<td>R 30</td>
<td>R 30</td>
<td>R 30</td>
<td>R 30</td>
</tr>
<tr>
<td>B-s2, d0</td>
<td>B-s2, d0</td>
<td>B-s2, d0</td>
<td>B-s2, d0</td>
<td>B-s2, d0</td>
<td>B-s2, d0</td>
</tr>
<tr>
<td>Insulation</td>
<td>A2-s1, d0</td>
<td>A2-s1, d0</td>
<td>A2-s1, d0</td>
<td>A2-s1, d0</td>
<td>A2-s1, d0</td>
</tr>
<tr>
<td>Internal surface of the ventilation gap (wind barrier)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 1** Brief overview of national fire safety requirements for façade elements (Finland, Germany, and Norway)

The topic of fire safety requirements has been continued within the research project smartTES. In addition to the basic TES façade, the fire safety requirements for extensions like additional rooftops, annexes or balconies have been summarized. A building extension might cause a change in building class which consequently has an effect on the fire safety requirements for the entire building. Therefore, an overview has been developed in which basic TES façade fire safety requirements are illustrated together with the consequences of various retrofitting measures on the entire building. The overview covers Finnish, German, and Norwegian fire regulations. The characteristics of different national requirements are compared with each other as to illustrate the national individual approaches within the European fire safety regulation landscape.
3.6 Book 6 – TES sustainability

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

Stephan Ott, TUM Technische Universität München

On the strategic level of sustainability, the TES methodology of refurbishment for residential buildings has been analyzed 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 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.

![Strategic Framework](figure17.png)

**Figure 17 – Structure of TES sustainability research tasks**

**Integration of TES into the life cycle of refurbishment projects**

*TES EnergyFacade* 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 measures 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 multi-criteria assessment with a variety of localized stakeholder priorities.

**TES on the level of environmental product declarations**

*TES EnergyFacade* 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 minimiz-
es 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 standardized 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 façade 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.
Figure List

Figure 1 - Building modernization as part of the wood value chain 2
Figure 2 - Holistic building modernization from design to assembly 3
Figure 3 - Ratio of time and cost during the planning and construction process 5
Figure 4 - production off-site, workshop environment 6
Figure 5 – Mounting of elements, Photo Stefan Thessenvitz 7
Figure 6 - Finland Virkakatu 8, Oulu. photo left: Simon le Roux, Aalto University. photo right: Jaakko Kallio-Koski M3 Architects. 9
Figure 7 - Grüntenstraße, Augsburg. photo left WBG, photo right Eckhart Matthäus 10
Figure 8 - Fredrik Selmersvei 4 in Oslo. photo: invisio 11
Figure 9 - Project Management and process chain 13
Figure 10 - Space module for a loggia extension, photo Wolfgang Huß 17
Figure 11 - Principles of a TES-integrated (left), TES-connected (middle), TES-envelope concepts, technical installations in the building envelope. 18
Figure 12 - Example: Horizontal section of vertical TES module with HVAC ducts. Alternative shaft solution covered with gypsum board and precast mineral wool inlay 19
Figure 13 - Principle of the passive heated envelope (right), usual retrofit of external walls (left) 20
Figure 14 - Overall chart diagram for the assessment of climate exposure and actions in design 21
Figure 15 - Fire testing, photo Stefan Loebus 23
Figure 16 – Overview of fire safety requirements and building regulations of national standards for Finland, Germany and Norway 25
Figure 17 – Structure of TES sustainability research tasks 26

List of Tables

Table 1 – smartTES - main characteristics 7
Table 2 - smartTES lessons learnt 8
Table 3 – Synopsis of research projects TES EnergyFaçade and smartTES 12

Abbreviations, Units

Abbreviations
abe  active building envelope
AHU  Air Handling Unit
bss  building service system
DHW  Domestic Hot Water
HVAC  Heating Ventilation Air Conditioning
IAQ  Indoor Air Quality
HRU  Heat Recovery Unit
rH  Relative Humidity
ITC  Information Technology and Communication
PENR  Primary energy content not renewable
PERE  Primary energy content renewable
PHBE  Passive heated building envelope
Qh'  Specific heat energy demand
Qe'  Specific end / use energy demand
Qe''  Annual primary energy demand
H'T  specific heat transmission transfer coefficient
Re  Resource efficiency (conservation of material)
TES  TES EnergyFaçade - timber based element system for improving the energy efficiency of the building envelope
WLC  Whole Life Cost