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Sustainable building project in steel

(SB_Steel)

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Final summary

The main outcome of the SB_Steel project was a pilot software for decision-making in order to support selection of steel-intensive solutions in the early phases of a building project that are known to be most crucial for the success of the construction work and for the performance and value of the completed building. The 'early design stages' were defined as phases of conceptual design and pre-design that are characterized by a lack of precise data and drawings. The piloting web-based service is made available to various operators of the steel construction sector by the European Convention of Constructional Steelwork ECCS. The organisation will promote its development in future.

The project produced two printed publications concerning design methods and processes of sustainable steel-framed and steel-intensive buildings based on research achievements. It organised four workshops in four European countries.

The R&D tasks of the project supported the development of approaches to steel-intensive new building and renovation and establishing of software:

- to build up a sustainability assessment methodology for a new or renovation building project
- to select a relevant set of key indicators and macro-components applicable for early stages of a building project
- to develop multi-criteria assessment method suitable for an early phase of a building project
- to develop a decision-making platform that supports selection of steel-intensive solutions
- to develop a pilot version of the software based on the combination of key indicators, macro-components and decision-making methodology.

The achievements of various work packages and tasks are summarised in the following.

Key indicators of sustainability and competitiveness of steel-intensive solutions (WP1):

Work Package 1 was focused to gather and preliminarily analyse basic research data concerning the state of the art on several research areas that are related to the sustainable steel-based building projects. Its aim was to propose a set of key indicators that are vital for a realistic sustainability assessment on a building. It studied also the various approaches to include sustainability objectives to building design processes. Work Package 1 was divided into four tasks.

Task 1.1 investigated influences of the sustainable construction on competitiveness of the steel-intensive building solutions, and especially on selection of framing solution. Interviews and surveys were regarded as the primary source of information. The literature survey relied on experiences of the partners and internet searches to a great extent. The Workshop was arranged in order to have feedback from various experts in the sector.

Results from questionnaires dedicated to manufacturers and suppliers showed that plenty of work has in fact been carried out starting at product and component level (environmental product declarations) and recently also at building level by providing system solutions and building concepts. The respondents considered steel as a structural material with a great potential in terms of sustainability mostly because it is recyclable. Combined use with other materials and integrated functionality are regarded as the way to overcome possible weaknesses of steel products in regards of energy-efficiency. Industrial manufacture of components reduces risks and accidents on building site that is an important social benefit.

The 1st Workshop "Competitiveness of steel buildings in changing markets toward sustainability" was organised in co-operation with the Technical Committee TC14 of ECCS "Sustainability and eco-efficiency of steel building" in accordance with the Technical Annex. The event took place a side-event of the EuroSteel Conference in Budapest on the 1st of September, 2011. The number of participants was 38. The main conclusions were summarized by the consortium so that continuous development of databases, simulation and assessment tools are necessary but at the same time the high-level engineering skills need to be developed. More emphasis should also be given on renovation projects and promotion of commonly accepted assessment methods.

In Task 1.2, sustainability assessment and rating systems were gathered, analysed and compared based on a literature survey on scientific publications and on the knowledge about the systems provided at the websites and brochures of the systems. Some of the most common assessment methods and tools both for environmental and holistic sustainability assessment were studied in detail. Furthermore, basic research data was gathered about concepts on energy-efficient buildings.

Several international assessment systems and tools were found to deal with all the dimensions of the sustainable construction. Seven systems were chosen for qualitative comparisons and evaluation about their usability in early stages of building design. The literature survey showed that the various systems have similarities at a very generic level including all the dimensions of sustainable building but they have significant differences in details and methods to collect data for analysis. It also showed that the early design stages are poorly included in the existing systems so far.

The requirements concerning energy consumption of a building were studied in the European context that has had a regulated basis since 2002. The recast of the Directive on Energy Performance of Buildings EPBD fixes 2020 as the deadline for all new buildings to be "nearly zero energy". Other concepts similar with the zero energy building were qualitatively studied. It was concluded that steel-framed and steel-intensive buildings can be designed according to a passive house concept in various climate zones of Europe. In connection with a well-insulated envelope and well-designed interior details, a steel building provides a high level of thermal comfort.

In Task 1.3 investigated approaches to design and assess both the technical quality and sustainability of a building project. This task supported the development of the concept of sustainable steel building from the viewpoints of a design process. Two fundamentally different approaches were identified that can be described as 'the Performance Approach' and 'the extended LCA' which both refer to setting and managing objectives of a building project and to various software tools. In the Performance-based design, the criteria are built up holistically. In the extended LCA, the environmental assessment methodology is the basis to which the performance ('functionality') issues are added. Furthermore, they involve requirement of integrated design from the very beginning of a new building project.

The definition of performance based approach to building design by CIB (1982) was regarded as rationale for the sustainable design process of a steel building: "a practice of thinking and working in terms of ends rather than means. It is concerned with what a building or a building product is required to do, and not with prescribing how it is to be constructed." The approach can be used whether the process is about an existing or new asset.

An introduction to decision-making methods was also reported as they are an essential part of selection between various building technologies. They are also embedded to sustainability assessment methods and rating systems.

Task 1.4 summarized the wide variety of research issues of the previous Tasks and proposed the list of key indicators to be investigated in the subsequent work packages. Two types of indicators were proposed to be considered: core indicators and additional indicators. Core indicators were meant for both the conceptual stage and pre-design stage, whereas additional indicators were regarded more suitable in the latter stages (pre-design). The core indicators are presented in Table below. In the Workshop, the social indicators were discussed and regarded as problematic for a decision-making aid due to missing metrics.

Table. Proposal of WP1 for core indicators suitable for concept and pre-design stages.

Environmental Indicators		
Environmental Impact	1	Global warming potential
	2	Depletion potential of the stratospheric ozone layer
	3	Acidification potential of land and water
	4	Eutrophication potential
	5	Formation potential of tropospheric ozone photochemical oxidants
	6	Abiotic Resource Depletion Potential for elements
	7	Abiotic Resource Depletion Potential of fossil fuels
Energy	8	Total Primary Energy Demand
Economic Indicators		
Life Cycle Costs	9	Construction costs
	10	Operation costs
	11	End-of-life costs

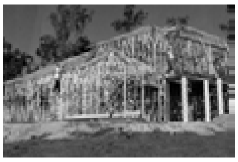
Concept of Sustainable Steel-Framed Building (WP2)

Work Package 2 comprised fundamental steps toward sustainability assessment in the early design stages of a steel-framed and steel-intensive new building. It was divided into four research tasks and the task to organise a Workshop and publish its Proceedings. WP2 produced one technical deliverable and the Milestone report ‘Requirements and recommendations for the decision-making platform and software’.

Task 2.1 established a basis for the databank of macro-components of steel-framed new buildings. Types of steel products used in different systems and structures of a building and for different purposes were listed at first. The design conditions were also described at a generic level based on the European system of essential requirements. Use of steel in the various sub-systems of a building and the typical related materials were summarized as presented below.

Building system	**Building elements**	**Materials**
Structure	Columns Beams Floors (including roof) Lateral Bracing systems	Steel structure Concrete structure (Timber structure)
Façade system	Glazing Window frames Closed window area´s Thermal insulation material	Aluminium curtain wall-systems (Brick in external wall) Thickness 50-150 mm, alternative materials
Roofing	Waterproofing Thermal insulation Moisture barrier	
Foundation	Not into account yet	
Infill/ partitioning	Light weight partition systems Ceiling systems Floor screeds	Lightweight steel + plasterboard Lightweight clay fired brick
Services	Material impact were assumed at a fixed amount	
Circulation (stairs, elevators)	Material impact to be disregarded at this stage	

Task 2.2 developed the structure and content for the data of macro-components. The macro-components were identified in the framework of the following matrix.

	Category 1 (C1)	**Category 2 (C2)**
Single & multi-family building (T1)		
Residential multi-storey buildings, apartment blocks (T2)		
Office buildings (T3)		

Categories of steel-framed buildings in the SB_Steel database.

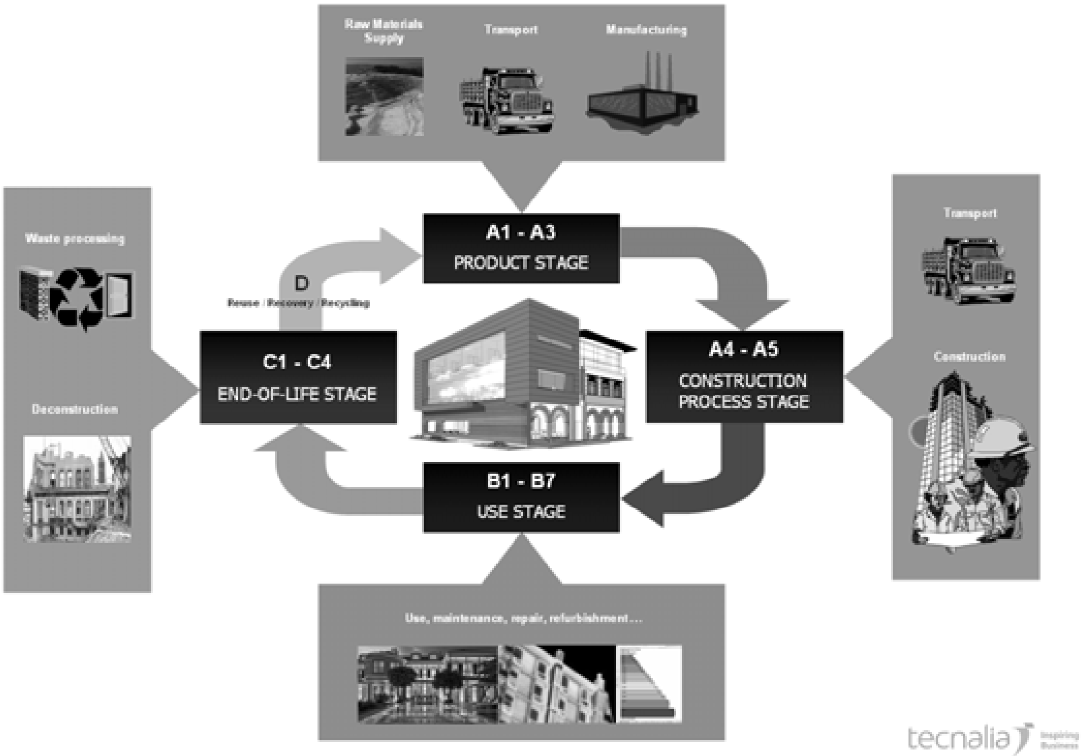
The database was further divided into different types of macro-components, regarding their function in the building.

The concepts presented in the European standard EN 15978:2011 – Sustainability of construction works – Assessment of environmental performance of buildings were adopted as the basis for preparing the data of macro-components.

Environmental profiles of macro-components

The international standards ISO 14040 and ISO 14044:2006 and the European standard EN 15978:2011 were adopted as the methodological basis for calculating and informing about environmental profiles of macro-components. The profiles make a major part of the macro-component data-base.

The environmental assessment of a building comprises four stages, plus a supplementary stage, ‘beyond the building life cycle’. According to EN15978:2011, the stages are the Product stage (module A1–A3), Construction Process stage (module A4–A5), Use stage (module B1–B7) and End-of-life stage (module C1–C4). The scope of the Supplementary stage (module D) is the reuse, recovery and recycling potential of, in this case, the macro-components, which represent one of the primary advantages of the sustainable design of steel-intensive buildings. The stages and their modules are presented in Figure below.



Life-cycle of a building CEN standard EN 15978.

Task 2.3 deepened the studies in WP1 concerning relationships between various approaches to assess whole-building performance and sustainability. It also intended to identify the competitive aspects of steel-framed buildings. The recent sectoral competitive analysis reports ordered by the European Commission and performed by Ecorys were regarded as important for perspectives of steel construction sector, too. They concluded the improved energy-, resource- and eco-efficiency as major sources for future competitive edge of the steel sector and the steel construction sector.

Recommendations of Ecorys (2008, 2011) were recognized to be in line with the vision and strategic research agenda of the European Steel Technology Platform ESTEP. It was concluded that the steel construction sector should elaborate more solutions and services for building level taking into account different products and systems. This would mean “a beyond product by product approach”: steel could offer ’holistic’ economic solutions not only in the energy efficiency area but also for all other areas of sustainable construction.

Task 2.4 developed the methods for the decision-making model to be incorporated to the tool that would support decision-making in early design phases in regards to sustainability objectives. Initially, core indicators proposed in WP1 consisted of environmental impacts and costs, and in an estimation of the operational energy demand. The additional indicators included the social indicators. Both can be regarded as important to be handled in establishing of a sustainable building project but the software development would need commonly approved and standardized methods.

The research made during the project showed that costs vary greatly from country to country, especially operational costs. This later would input several constrains and variables to the assessment method, requiring much more data from the users, which would contradict the main objectives of the tool: to be simple and easy to use. In what regards social aspects, no exact assessment models are standardized by now. In this sense, social aspects should be incorporated when more accurate standard methods are available. For these reasons, cost and social indicators were agreed to be excluded from the case studies and the software. The indicators which were really included in the case studies and tool, both for conceptual and preliminary design phases are the ones presented in Table below.

Key indicators included in the software for both conceptual and preliminary design phases.

Environmental impact categories	Unit	Energy related indicators (kWh/Year)
Global warming potential	Kg CO_2 eq	Heat transfer (heating and cooling season)
Depletion potential of the stratospheric ozone layer	Kg CFC11 eq	Heat Gains (heating and cooling season)
Acidification potential of land and water	Kg SO_2 eq	Energy needs for heating
Eutrophication potential	Kg $(PO_4)^{-3}$ eq	Energy needs for cooling
Formation potential of tropospheric ozone photochemical oxidants	Kg C_2H_4 eq	Energy needs for DHW
Abiotic resource depletion potential for elements	Kg Sb eq	Delivered Energy (for heating, cooling, DWH, total)
Abiotic resource depletion potential for fuels	MJ	Renewable Energy (for heating, cooling, DWH, total)
		Primary energy (for heating, cooling, DWH, total)
		Building's total energy needs

The energy related indicators were incorporated as a module to the software based on theoretical studies on several parameters influencing the total energy demand and energy-efficiency. The methodology to assess the energy-efficiency at early design stages required the adoption of simplifying assumptions concerning the building shape, the structural system, the building envelope and the interior finishes. The internal and external components of the building were selected from the database of macro-components produced in the project. The macro-components enable the automatic calculation of required thermal properties, such as the U-value and the heat capacity.

The tool for energy calculation was developed in agreement with relevant European and International standards. This tool enables calculation on a monthly basis for: (i) heating mode; (ii) cooling mode; and (iii) domestic hot water DHW production. ISO 13790 (2008) was selected as the base standard, which refers to specific calculations in other standards. The importance of the DHW production in the building's energy consumption was addressed in accord with the guidance of EN 15316-3-1 (2007). In national building codes, procedures may also be given for simplified approaches but for the software the common basis was regarded as more reasonable.

The 2nd Workshop "Concepts and Methods for Steel Intensive Building Projects" was organised in co-operation with the Technical Committee TC14 of ECCS "Sustainability and eco-efficiency of steel building" and the WP3 of ESTEP "Construction and Infrastructures Sector". The event took place in Munich on 8th of May, 2012. Among speakers, the World Steel Association and Eurofer were represented. The number of participants was 48.

Concept of sustainable steel-intensive renovation (WP3)

The Work Package 3 studied applicability of the assessment methods proposed for the early design stages of new building projects to renovation projects, focusing on deep structural renovations and functional upgrading. The word renovation was defined as activities aiming to improve technical, functional or economic value of the building, which are not ordinary maintenance or cleaning. Terms such as improvement, adaptation, upgrading, rehabilitation, modernization, conversion, retrofit, refurbishment and repair were included to the renovation concept. Activities may concern structural, technical or space systems of the building.

T3.1 studied the potential of constructional steelwork in the renovation sector, markets and needs in particular in Spain and Finland. Use of steel in renovation projects was categorized as structural and functional. In the latter category, energy efficiency improvement has become a major type of activities. In strengthening projects, amount of on-site and manual work can be substantial. In functional use, other properties of steel than strength of material are of importance, too. Sustainability also means the ability to accommodate to changed requirements and take up the challenge of time. The benefits of steel-intensive solutions in building renovations are presented in Table below.

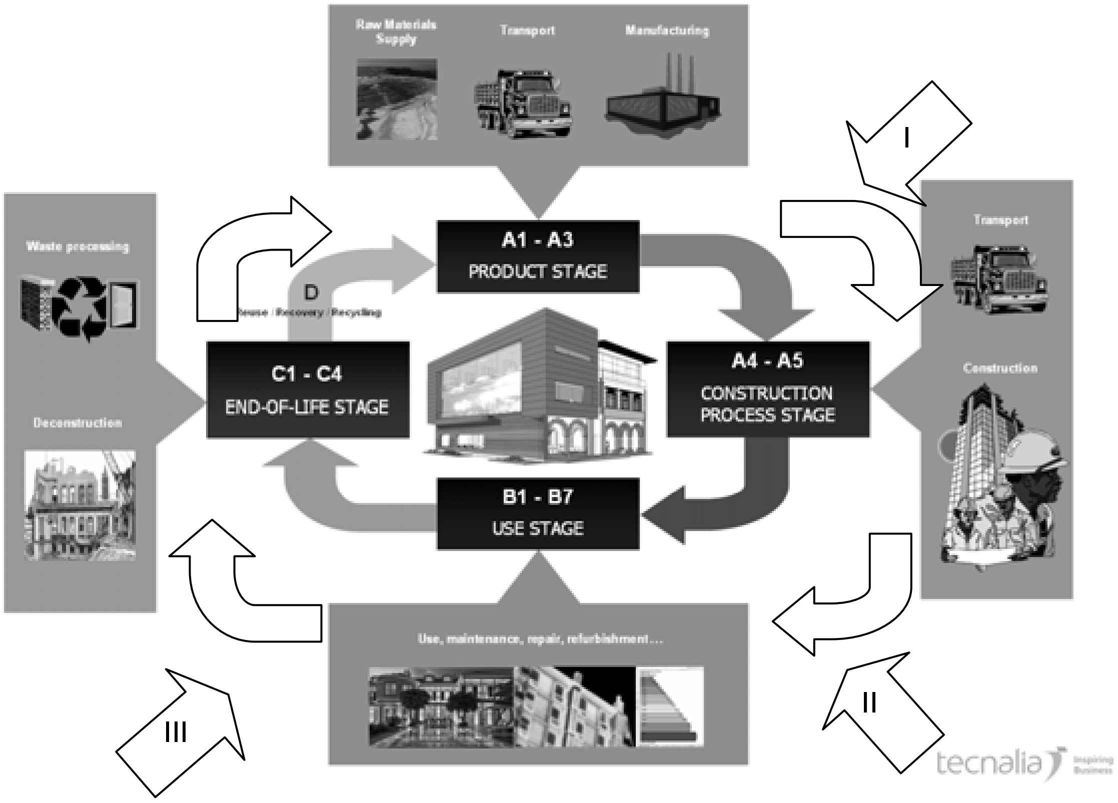
Benefits and competitive edge of steel-intensive solutions in various renovation projects.

Scale and type	Degree of change	Objectives Type of renovation	Benefits and competitive edge of steel
Small/ Type I	Low	Upgrading of surfaces, minor extension; strengthening of existing structures; loft conversion; change of roof shape; Type I allows use of the existing building	For strengthening, practically no substitutes on markets; steel products and components available for minor and small scale renovations; roofing solutions and services highly competitive
Medium/ Type II	Substantial	Strengthening of a building externally; major upgrading of surfaces, structures or services, structural alterations; modular extension on a roof; several simultaneous objectives Type II may change the use of a building	For strengthening, practically no substitutes on markets; many types of steel-based solutions available for major envelope renovations
Large/ Type III	Drastic	Reconstruction of new building behind existing façade; extensive alterations for conversion to new use or occupancy Type III demolishes major parts of the existing building and may change totally the function of a building. Occupants need to move out.	Steel and composite structures allow efficient processes and logistics

T3.2 studied special features of renovation projects in respect to the various sustainability indicators and compared the renovation projects with new buildings. Motivation of a renovation project may often be related to social indicators like for example to accessibility, and development of renovation concepts and services need to cover these kinds of indicators, too.

A renovation project can take place at various ages of a building during the use stage. Thus a renovation project may present all the stages of a life-cycle simultaneously with the use phase of the existing building. Renovation types II and III means in practice a second life-cycle of a building. In fact, instead of a unique cycle, due to the combination of existing elements and new added ones, various cycles can appear overlapped with different stages of development coexisting (Figure below).

Steel-based solutions were regarded as highly competitive in the renovation types I and II when renovation concerns strengthening of existing structures or structural renovation. In some occasions, fibre reinforced plastics are used to same purposes as steel but steel's position is strong. In type III renovations, competitiveness depends on the level of prefabrication and services offered to building owners. Tightening European regulation has directed high interest in renovation projects in which envelope structures are upgraded; steel based solutions comprise new roofing and facades with thermal insulation. These solutions also allow architectural changes in the appearance of a building; additional components such as elevator shafts and balconies can be included to improve accessibility and well-being. Extensions on roofs or around the existing building are often benefiting from steel construction technologies thanks to, for example, lightness, strength, precise tolerances, easy assembly and logistics. However, the substituting solutions are available and competition resembles that in the new building segment.



Life-cycle of an existing building during a renovation project: In type I project, small-scale works are made to the building; in type II renovation, parts of the existing building is in use when medium-scale changes are made around and inside the building (phases A1–B7, type II renovation); in type III renovation, parts of the building are demolished and replaced by new solutions.

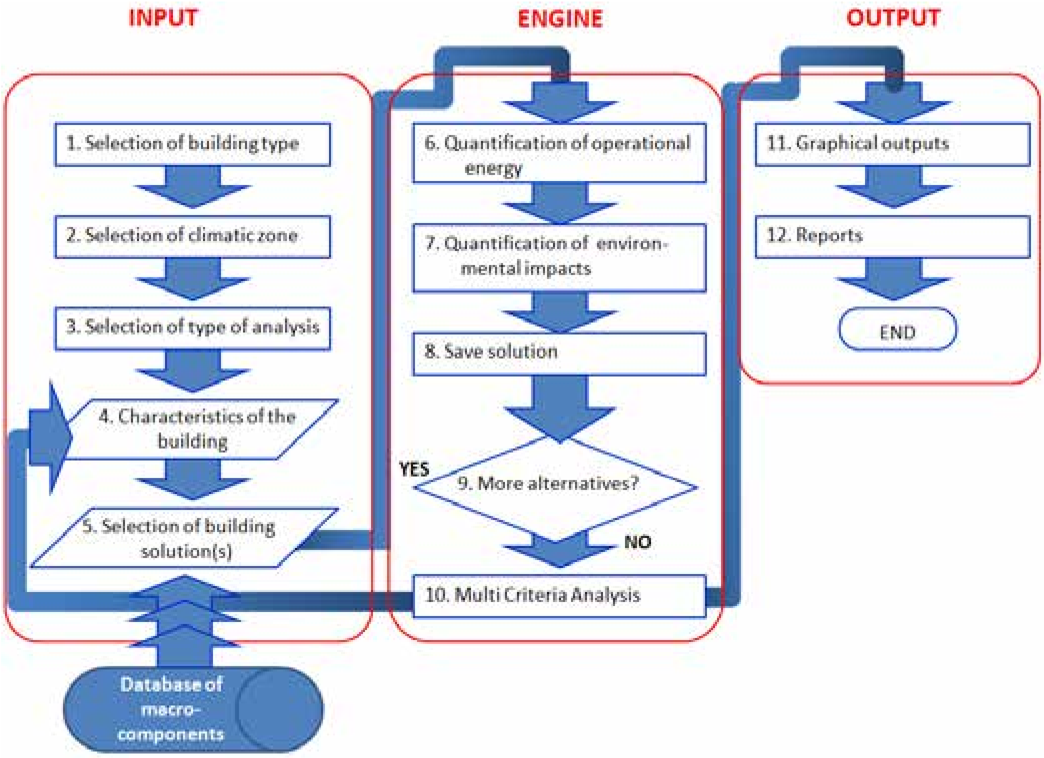
Task 3.3 considered the suitability of macro-component approach to renovation projects in the context of the two main renovation types. In principle, the envelope macro-components and their data can be prepared like for new buildings. The same holds structural strengthening but the benefits of the approach for decision-making in early design phases are smaller as the uniqueness of solutions is obvious. The set of indicators were also assessed, and it was observed that in practice a limited number of indicators may be reasonable. For example, it is possible that selection of solutions for energy renovation is made solely based on energy consumption as the indicator. Additionally, renewable and non-renewable sources of energy can be valued. Other indicators can be selected according to simultaneous objectives such as indicators for comfort (indoor air, noise, appearance).

Task 3.4 prepared the model for incorporation of renovation projects to the decision-making platform based on the case studies and preceding tasks. The renovation macro-components were developed and compiled alike to what was developed for new buildings macro-components database. The procedure adopted to perform the macro-components analysis was the same as developed for new buildings. The structure developed for new buildings was also observed as usable for renovation cases. The structure is divided in three stages: (i) input, (ii) engine and, (iii) output. The input phase collects general data regarding the building and the type of renovation, gave by the user. The engine part, quantifies the impacts (environmental, economic and social) for each solution. In this case, renovation projects, also the original building shall be addressed in order to identify the improvement potential of each of the solutions considered. The calculations and the decision-making methods used for renovation projects are the same as the ones presented for new buildings. At last, the output phase gives the results obtained.

Development of Environmental Software Tool (WP4)

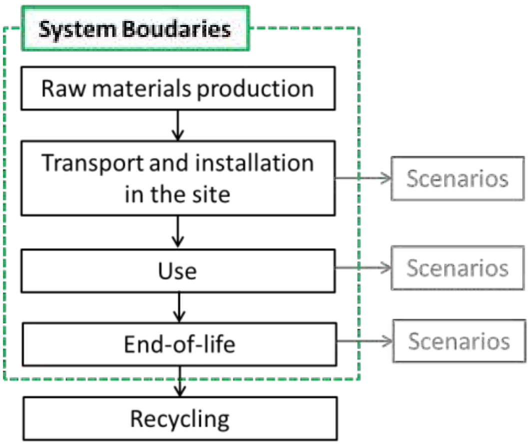
Work package 4 produced the decision-making aid for sustainable design of steel-framed and steel-intensive building projects. The software can also be used for renovation design when the building components are presented as macro-components.

Task 4.1 developed the general framework for software that handles the environmental assessment and the energy performance of a building in the early stages of design. Therefore, the aim of the software was set as the evaluation of different building solutions in two distinct stages of a building project: (i) the conceptual stage, and (ii) the pre-design stage. In the conceptual stage in particular, the availability of data is scarce. Thus, two different algorithms were developed in order to address both stages of design. Software tool aimed at a quick evaluation, at the pre-design stage, of the sustainability of steel-framed buildings, from the points of view of environmental life-cycle performance and energy efficiencym with a user-friendly interface concerning both the input and output procedures. The scheme of the tool was develop parallel in WP2 as presented below.



Flowchart of the software.

Task 4.2 implemented the macro-component approach to the software. The quantification of environmental impacts of a building was based on different scenarios at three levels, i.e., materials/products, macro-components and building, according to EN 15978:2011 and EN 15804:2011. Both standards propose the quantification (and presentation) of potential environmental impacts and energy need through a modular system consistent with the several stages of the life cycle of materials/products and building. Loads and benefits resulting from reuse, recycling and energy recovery are assigned in Module D, which is an optional module. In a cradle-to-grave analysis the general system boundary of the macro-component is illustrated in Figure below.



Macro-components system boundaries.

Some stages were quantified based on scenarios. In order to describe scenarios in a transparent and objective way, a series of tables were formulated to allow a complete description of the scenarios considered for a given stage.

Task 4.3 was dedicated to development of the algorithm for the quantification of the energy component of the building. The software for the operational energy quantification of the building in the preliminary stage and in the conceptual stage of design was built on three main modules: the input module, the engine, and the output. The module of input data was sub-divided into three sub-modules: input of climatic data, input of the characteristics of the building's envelope, and input of the systems integrating the building. In the first module, input of climatic data, two major climate parameters must be defined in order to perform energy need calculation: i) air temperature; and ii) solar radiation on a surface with a given orientation.

The calculation of the energy needed for space heating and cooling is performed taking into account a monthly quasi-steady state method, which relies in correlation factors to simulate the dynamic effects associated with this kind of thermal balance problems. For the space heating, the effect of higher gains (solar and internal) than heat losses, which leads to an overheating effect, is accounted for through the heating utilization factor. In the case of the energy for space cooling, the utilization factor is applied to the heat transfer from the interior of the exterior (losses) in order to include the effect of the losses that are not used to lower cooling loads (periods of low interior temperature). Furthermore, intermittent cooling and intermittent heating situations are addressed in this tool. Based in the calculation procedures, the building is classified in terms of energy efficiency.

T4.4 was dedicated to implementation of the software. This was made in two different components: 1) a public website enabling the assessment of building sustainability, and a private back office for the parameterization of the website.

In ***Task 4.5***, validation of the software was made through a case study. The case study was assessed by the developed tool over the two stages of design considered in the tool: the concept stage and the preliminary stage. Then, the same case study was performed by other available software, namely, GaBi 6 (2012) and DesignBuilder (2012), for life cycle assessment and energy quantification respectively. The case was a two-storey residential building located in Coimbra, Portugal composed of two storeys, with a light-weight steel frame. The results of the several design stages were compared with advanced analyses in order to assess the accuracy of the developed tool.

Case-studies (WP 5)

Work package 5 ran parallel with the other work packages through providing architectural and structural design data and drawings and providing environmental and energy-related data of macro-components.

Task 5.1 prepared the template for gathering building data needed in sustainability assessment. It gathered the architectural briefing information and selected a preliminary set of potential case studies among partners. It appeared that University of Timisoara had already a valuable library of real building projects.

Task 5.2 continued collection and organising of basic building data on chosen case studies. The structural design was made for two different design conditions taking into account various climatic regions and the specific regulations of the country.

Task 5.3 localized the design conditions of Romania to Northern and Southern conditions. A case study was also made adapting the Portuguese (Coimbra) case to different climates. The environmental impact data were calculated in Timisoara for most of the cases, and energy-related indicators were calculated by each beneficiary. Papers were prepared based on calculations which finally informed about the data of selected macro-components and were incorporated to the databank of macro-components.

The 3rd Workshop was organised in Task 5.4 in Timisoara on 29th of January, 2013. Proceedings were prepared based on the Workshop papers.

Dissemination (WP 6)

Work Package 6 dealt with the dissemination and public consultation concerning the results of the research project.

Task 6.1 paid attention to communication with different stake-holders and bringing them aware about the project. A list was compiled containing organizations/forums/associations etc. in which SB_Steel partners are involved. This list was completed by all the partners and verified for sufficiency, covered scope and possible additions. A number of organisations were mentioned, eg. VTT in CEN TC350 and SB_Alliance, Luis Braganca is the President of iiSBE, Heli Koukkari is a member of ESTEP WG3. Other contacts include other activities like EU-projects (OpenHouse/ Acciona plus experts, Superbuildings/ VTT, Cileccta/ Acciona, Lense, Building Up/ Heli Koukkari as an expert). The contact list was used for search of keynote speakers to and advertising of Workshops. Presentations of the SB_Steel project were also given in the meetings of the other organisations (iiSBE, ECCS TC14, ESTEP). The Workshop 1 was organised in co-operation with ECCS as a side-event of the EuroSteel Conference in Budapest. The Workshop 2 was organised in co-operation with ECCS and ESTEP WG3. Keynote speakers were from Worldsteel Association, Eurofer, FOSTA and BauforumStahl among others.

Task 6.2 produced a technical booklet based on design examples that were used to support and test the software. The design examples were planned according to the same climatic zones as the case studies. The building data inputs were also the same as in case studies.

The most appropriate case studies that effectively display the usage and potential of the SB-Steel software were selected for inclusion in the case study booklet. Some of the design examples were presented completely showing the different stages of the software and its use, some were only showing the report that the software send to a user's e-mail. The full example is introduced below concerning the French case reported by University of Minho.

Task 6.3 was implementation of the website as reported in WP4.

The 4th Workshop ('open meeting') held in Guimarães, Portugal on the 25.7.2013 aimed to introduce the new decision-making software developed in the project, and its background and use. It was organised as a side-event of the Conference on Structures and Architecture ICSA 2013 and in co-operation with the Technical Committee TC14 "Sustainability and eco-efficiency of steel building" of ECCS. 35 persons attended.

1. Objectives of the project

The project strengthens the competitive edge of steel-intensive construction by providing concepts of sustainable steel building both for new build and renovation, and based to this approach, a novel decision-making platform for the early phases of a building project will be developed. The sustainable building or renovation concept comprises the key indicators by which a building or renovation project can be steered, and later on the overall performance of a completed building can be monitored and evaluated. The early phases of a building project are known to be most crucial for the success of the construction work and for the performance and value of the completed building. The importance of improved knowledge basis and methods for the early phases is highlighted by the fact that framing and typical related technologies are also selected then. The platform is available to various operators of the steel construction sector. The piloting web-based service will be run by the European Convention of Constructional Steelwork. In order to achieve the goals, the R&D objectives of the project are

- to build up a sustainability assessment methodology for a new or renovation building project
- to develop multi-criteria assessment method for an early phase of a building project
- to develop knowledge base for performance-based requirements management
- to develop a decision-making platform that supports selection of steel-intensive solutions.
- to develop a piloting version of the service concept.

The R&D added value of the proposal is at first a concept of a sustainable design and building process for steel-intensive solutions that can be utilised to knowledge and quality management, and secondly an adoption of multi-criteria decision-making platform with an environmental evaluation to the early phases of a steel-intensive building project.

2. Description of activities and discussion

2.1 *Key indicators of sustainability and competitiveness of steel-intensive solutions (WP1)*

The Work Package 1 gathered basic research data and studied state of the art and best practices in the fields that are related to the framework of sustainable design of steel-framed and steel-intensive building projects. It established the common framework to the succeeding work packages and presented the methodological approaches to the case-studies and the decision-making platform. It proposed a set of key indicators essential for realistic sustainability assessment of steel-based building and renovation projects.

WP1 was divided in four Tasks from which three were further divided in three Sub-tasks. Outcome of three Tasks were summarized in one technical deliverable and the milestone report was produced based on Task 1.4. In addition, several interim working documents were compiled collaboratively at the Sub-Task level.

2.1.1 Market study of competitiveness of steel-intensive solutions from the point of view of sustainability (Task 1.1)

Task 1.1 investigated influences of the sustainable construction on competitiveness of the steel-intensive building solutions, and especially on selection of framing solution. Interviews and surveys were regarded as the primary source of information. The literature survey relied on experiences of the partners and internet searches to a great extent. The Workshop was arranged in order to have feedback from various experts in the sector.

Interviews, website visits and surveys

Close to twenty site visits to websites of co-operation organisations (see Table 1 about results), companies and research centres were the main source of written information.

Table 1. The arguments in favour of steel-intensive construction based on website visits.

Argument	Descriptions
Recycling	inevitably, no quality loss, use in same applications – multi-cycling
	Recycled content the highest of any building framing material Recycling rate of 98%, the highest of any building framing material
	saves nature, energy, waste and emissions
	easy to separate from waste
	the first and only true cradle-to-cradle building framing material
Durability	long life spans minimal needs of maintenance
Strength to weight-ratio	“relative lightness” material and energy savings
Embodied energy, embodied carbon	Strength-to-weight coupled with a low carbon footprint (0.73 tons of CO2 per ton of steel) results in an overall reduction of the embodied carbon of a typical structure as compared to buildings constructed with other framing materials
	Significant improvement in production technologies since 1990
Material efficiency	almost 100% of materials converted to products and by-products
Water recycling rate	Superior water resource management: 95% water recycling rate
Suitability to several applications	frames, facades, composite structures, staircases, roofings
	necessary for concrete and composite structures
Long-spans	flexibility/adaptability in use phase; changes in use, layout and size
	High-quality, small tolerances
	Off-site construction
	Suitable for modular construction
Reducing operational energy, energy-efficiency	Good design and specification of low and zero carbon technologies
	Novel façade components with improved air-tightness
	Metal roofs with heat-deflecting coatings and finishes can save building owners up to 40% in heating and cooling costs

	Pre-painted or granular coated metal roofing systems not only reflect solar energy but also cool the home by re-emitting most of what solar radiation is absorbed.
	easy integration of mechanical systems, resulting in low floor-to-floor heights, less building volume, and lower energy consumption
	Facilitate the use of external insulation techniques which are favourable to the energy balance and allow the construction of buildings having a low inertia which reduces heating needs
Indoor air quality	dry construction technologies reduce problems caused by moisture
Extended service life	Thanks to long-spans, connections and lay-out, easy modifications
Rapid erection	Off-site component manufacture
	Products pre-engineered to correct dimensions, small tolerances
	CAD-CAM and BIM implementation allows accurate design and manufacture as well as efficient site planning
	Just-on time deliveries
Reducing CO2 emissions	CO2 reductions through optimized logistics (truck to track, optimized transport routes)
	Use of steel in applications allow for substantial reduction of CO2 emissions
Deconstruction, dismantling	
	Constructional steel components are often joined in a manner that facilitates easy deconstruction
Off-site manufacture	Facilitates resource management, reduction of waste
	Improved productivity/ efficiency, industrial quality, preciseness
	Reduction of worker's travelling
	Improved logistics and regional supply
	Improved occupational health
	Life-long learning, stabile positions
Input to the building stock	Suitable and capable for rapid transform of the European building stock – new and renovation
	Improving aesthetics and functionality of huge areas
Input to energy technologies	Energy technologies (materials for key components to increase efficiency in caloric power plants, materials for renewable energy sources, hydropower, wind power, solar-thermal, photovoltaics, etc., materials for energy transmission and storage)
	Integrated solar panels for envelopes
	Eco-piles for foundations to contribute in soil energy collection
Input to transport technologies	Steel contributes to all technology developments
Input to economies	The steel industry and steel construction sector contribute to national and global economies advantageously through jobs and living environment

The results from web-site visits gave a comprehensive picture about the arguments used to convince markets, public authorities and legislators. The most important arguments at the moment are about environmental impacts of steel production and steel-intensive construction (recyclability, reusability, resource-efficiency). The economic and social impacts are dealt with at some websites. The critical issue is the carbon footprint of the steel production, in particular due to the political pressure in Europe. The steel industry has strongly opposed the rapid tightening of regulation although it can show remarkable achievements in improving its production technologies worldwide.

Three different questionnaires were prepared in order to gather information about design and construction practices:

- Questionnaire dedicated to Designers (Germany, Spain, Luxembourg, Slovenia, Belgium);
- Questionnaire dedicated to Whole Building Solution Suppliers (ArcelorMittal-Spain, Tata Steel – UK; Ruukki Construction, Finland; Lindab Europe, Switzerland; ArcelorMittal-Commercial Sections)
- Questionnaire among the project partners (Mostostal, Acciona, Tecnalia).

In addition, AUTH and VTT mapped the situation among the structural designers.

The results showed that Design Offices which have answered to the questionnaire are quite aware of the sustainability issues regarding steel. A commonly shared view was that steel is a sustainable material mainly because of its recyclability. In practice, the need of sustainable design competences is however still small in ordinary building projects. One public building example was the only experience of design offices involved in the survey, but on the other hand it can be a sign of a gradual turn.

Results from questionnaires dedicated to manufacturers and suppliers showed that plenty of work has in fact been carried out at first at product and component level (environmental product declarations) and recently also at building level by providing system solutions and building concepts. The respondents consider steel as a structural material with a great potential in terms of sustainability mostly because it is recyclable. Combined use with other materials and integrated functionality are regarded as the way to overcome possible weaknesses of steel products in regards of energy-efficiency. Industrial manufacture of components reduces risks and accidents on building site that is an important social benefit.

The knowledge increasingly asked from supplier and designers during a building project includes the following aspects:

- Reliable and accessible data on environmental impacts of steel and other materials used in steel-intensive construction.
- Use of the environmental data. The carbon footprints are commonly available as a part of environmental product declarations. Reliability of calculators is asked. Other impacts are less transparent. Impact evaluation is more complex.
- User-friendly methods and tools. Common information about the certification methods and their differences.
- Deconstruction and reuse scenarios. While recycling is one of the end scenarios for steel building components which entails a relatively decreased environmental load, the reuse of steel members can ensure even greater benefits, because of the total avoiding of the manufacturing process. However, in order to take advantage of such scenarios it is necessary to incorporate these requirements in the design process of the building.

The 1st Workshop "Competitiveness of steel buildings in changing markets toward sustainability" was organised in co-operation with the Technical Committee TC14 of ECCS "Sustainability and eco-efficiency of steel building" in accordance with the Technical Annex. The event took place a side-event of the EuroSteel Conference in Budapest on the 1st of September, 2011. The number of participants was 38. More information about the Workshop is presented in Chapter 3.8.

2.1.2 Systems and indicators of sustainable steel-intensive building (T1.2)

Sustainability assessment and rating systems were gathered, analysed and compared based on a literature survey on scientific publications and on the knowledge about the systems provided at the websites and brochures of the systems. Some of the most common assessment methods and tools both for environmental and holistic sustainability assessment were studied in detail.

Approaches to assess sustainability

Several international assessment systems and tools were found to deal with all the dimensions of the sustainable construction. They were as follows: BREEAM (Building Research Establishment Environmental Assessment Method) in the UK, LEED (Leadership in Energy and Environment Design) in the USA, HQE in France, DGNB in Germany, SB Tool (Sustainable Building Tool of the international initiative for the Sustainable Built Environment iiSBE), EcoProP (VTT, Finland) and CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) from Japan. In addition, an FP7 project LENSE was developing a harmonised European system. Seven systems were chosen for qualitative comparisons and evaluation about their usability in early stages of building design (see Tables 2–6).

It was observed that early design stages (programming/concept/ briefing) are addressed in minimal detail in international sustainability guidelines and recommendations. Only the North American programs provide recommendations for the programming phase. These guidelines recommend establishing a design team consisting of experienced professionals who will be involved with the sustainable building design work. The extent to which the design team should plan and organize their efforts before actual design work is however discussed only in general terms. The CASBEE program from Japan is developing a pre-design tool for their evaluation process. Some emphasis on the design programming phase is prudent, because it sets the tone for all remaining design and construction activities and hence will affect all aspects of the building life cycle. The American LEED program awards points to teams that include LEED accredited professionals.

Table 2. Summary of issues considered in the holistic systems.

BREEAM	HQE	DGNB	SB Tool	LENSE	CASBEE	LEED
1. Management	1. Harmonious relationship of the building with its immediate environment	I. Environmental quality	A. Site selection, project planning and development	1. Environmental issues	Q. Quality of building performance	1. Sustainable site
2. Health and well-being	2. Holistic choice of construction process and products	II. Economical quality	B. Energy and resource consumption	2. Social issues	Q1. Indoor env.	2. Water efficiency
3. Energy	3. Low-nuisance construction site	III. Socio-cultural and functional quality	C. Environmental loadings	3. Economic issues	Q2. Quality and service	3. Energy and Atmosphere
4. Transport	4. Energy management	IV. Technical quality	D. Indoor environmental quality	4. Climate change	Q3. Outdoor env. on site	4. Materials and resources
5.Water consumption	5. Water management	V. Process quality	E. Service quality	5. Accessibility		5. Indoor environmental quality
6. Materials	6. Operational waste management	VI. Site quality	F. Social and economic aspects		L. Environmental load	6. Innovation and design process
7. Land use	7. Management of upkeep and maintenance		G. Cultural and perceptual aspects		L1. Energy	
8. Ecology	8. Hygrothermal comfort				L2. Resources and materials	
9. Pollution	9. Acoustic comfort				L3. Off-site env.	
	10. Visual comfort					
	11. Olfactory comfort				BEE. Building environmental efficiency Q/L	
	12. Sanitary quality of interior areas					
	13. Sanitary quality of the air					
	14. Sanitary quality of water					

Table 3. Weights against issues in different rating systems(in HQE no specifications).

BREEAM	DGNB	SB Tool**	LENSE	CASBEE	LEED
Management: 12%	Ecological Quality: 22.5%	A. Site selection, project planning and development	Climate change: 150 points	Q1 Indoor environment: 0.4	Sustainable sites: 26 points
Health and Well-being: 15%	Economical Quality: 22.5%	B. Energy and resource consumption	Resource use: 100 points	Q2 Quality of service: 0.3	Water efficiency: 10 points
Energy 19%	Socio-cultural and Functional Quality: 22.5%	C. Environmental loadings	Biodiversity: 100 points	Q3 Outdoor environment on site: 0.3	Energy and atmosphere: 35 points
Transport: 8%	Technical Quality: 22.5%	D. Indoor environmental quality	Env. and Geographical risk: 50 points	LR1 Energy: 0.4	Materials and resources: 14 points
Water: 6%	Process Quality: 10%	E. Service quality	Occupant Wellbeing: 75 points	LR2 Resources and materials: 0.3	Indoor environmental quality: 15 points
Materials: 12,5%		F. Social and economic aspects	Security: 30 points	LR3 Off-site environment: 0.3	Innovation and design: 6 points
Waste : 7,5%		G. Cultural and perceptual aspects	Social and cultural value: 65 points		Regional priority: 4 points
Land use & Ecol.: 10%			Accessibility: 70 points		
Pollution: 10%			Financing and management: 50 points		
			Whole life value: 60 points		
			Externalities: 50 points		
100%	100%		800 points		110 points

** Weights to be adjusted up or down by authorized third parties according to regional needs. The sum total of all active criteria is always 100%.

Table 4. General comparison of the tools.

	BREEAM	HQE	DNGB	SB Tool	LENSE	CASBEE	LEED
Geographical range	UK	France	Germany	Global	European	Global	USA
Usage of tool	Import data for third party to asses	Simple /open, linked to the French regulations		Complex spreadsheet		Complex spreadsheet and manual	Import data for third party to asses
Outcome	Poor, good, very good, excellent environmental performance	Very good level, good level, basic level	Bronze certificate,Silver certificate, Gold certificate	-1 to +5 scale for each environment-tal issue	Weighting system that reflect regional priorities	Score graphs, labelling (poor – excellent sustainable building)	Labelling (certified – platinum performance)

Table 5. Comparative analysis of sustainability tools with regard to main issues.

Issue	BREEAM	HQE	DNGB	SB Tool	LENSE	CASBEE	LEED
Site	√	√	√	√		√	√
Indoor environment		√	√	√		√	√
Energy	√	√	√	√		√	√
Materials resources	√	√	√	√		√	√
Water	√	√	√	√		√	√
Transport	√		√		√		√
Health	√	√			√		
Social			√	√	√		
Economic			√	√	√		
Comfort		√	√			√	
Management		√	√				
Services						√	
Long term performance		√		√			
Design aesthetics							√
Functionality	√	√	√	√			

Usability criteria of various assessment systems in early design stages were based on six aspects and the outcome of comparison between the selected systems is presented in Table 6.

Table 6. The usability criteria of various sustainability assessment methods.

Usability criterion	BREEAM	HQE	DNGB	SB Tool	LENSE	CASBEE	LEED
Relevance	Partially	Partially	Partially	Partially	Partially	Partially	Partially
Coverage	Partially	Partially	Yes	Yes	Partially	Partially	Partially
Measurable	Yes	No	Yes	Yes	Yes	Yes	Yes
Applicability	Yes	Partially	Partially	Yes	Partially	Yes	Yes
Availability	Yes	No	No	Yes	No	No	No
Technical future	Partially	Partially	Partially	Partially	Partially	Partially	Partially

The literature survey showed that the various systems have similarities at a very generic level including all the dimensions of sustainable building but they have significant differences in details and methods to collect data for analysis. Even the environmental assessment may be based on qualitative assessment although quantitative life cycle assessment methods (LCA) are available which essentially builds on environmental impact data of building products.

CEN TC 350 suggests the outputs indicators for environmental impacts presented in Table 7.

Table 7. Environmental indicators currently suggested in the CEN/TC 350 standards.

Indicator	Unit
Contribution to global warming	kg CO_2 equiv
Destruction of the stratospheric ozone layer	kg CFC-11-equiv
Acidification of land and water	kg SO_2-equiv
Eutrophication	kg PO_4-equiv
Formation of ground level ozone	kg C_2H_2 equiv
Radioactive waste	kg, MJ
Use of renewable/non-renewable primary energy	MJ
Use of freshwater resource	m^3
Use of renewable/no renewable (other than primary) energy	kg
Use of recycled/reuse resource	kg
Material for recycling/energy recovery	kg, MJ
Non-hazardous/hazardous waste	kg

Energy-efficiency requirements and new building concepts

The requirements concerning energy consumption of a building were studied in the European context that has had a regulated basis since 2002. The recast of the Directive on Energy Performance of Buildings EPBD was approved on May 2010. It fixes 2020 as the deadline for all new buildings to be “nearly zero energy” (and even sooner for public buildings – by the end of 2018). However, Article 2(1a) gives a purely qualitative definition:

> ‘A “nearly zero energy building” is a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.’

The basic principle of the EPBD and its recast has been that the overall consumption is calculated taking into account all the means energy is consumed and produced. At the end, the energy counts that is purchased on the market.

Other concepts similar with the zero energy building were qualitatively studied. The Passive House concept refers to a construction standard that can be met using a variety of technologies, designs and materials. It is basically a refinement of the low energy house standard that does not presume a conventional heat or cool distribution system. Energy saved on heating is 80% compared to conventional standards of new buildings.

It was concluded that steel-framed and steel-intensive buildings can be designed according to a passive house concept in various climate zones of Europe. In connection with a well-insulated envelope and well-designed interior details, a steel building provides a high level of thermal comfort. The energy consumption of a steel building caused either by heating or by cooling demands, depends critically on the design quality of the building, its function and its interaction with the environment.

The steel building geometry and the distribution of its mass are additional factors relevant to heat flow. Both façades, closed and glazed, perform differently in summer and winter. Increasing the building surface in relation to the heated volume, results in a higher demand for heating energy. The heating demand of a multi-storey steel building is highly dependent on the thermal insulation of the building envelope and its air-tightness. The steel building is influenced not only by design of an efficient structure, but also by know-how of the relationship between structure and building envelope.

There are alternatives to today’s energy-consuming houses, including houses built not only to save energy but to produce it as well. There is a long-standing interest in energy efficient houses in Europe, but now there is increasing interest in so-called energy plus houses, which generate more energy than they consume. A Plus-energy house can produce four times the energy that is consumed by occupants; innovative total energy concept with a combination of passive and active features; reduction of the energy requirement by high-insulation building envelope and own-developed solar shield; base energy loads conducted away by means of radiant cooling; Demand-based fast cooling by means of air conditioning system with connected Phase Changing Materials store.

Examples of sustainable steel building projects – assessment and certification

Five examples of steel building projects were collected in order to get glimpses how the sustainability assessment has been implemented in building projects. Four of the cases were in the UK, three of them were new buildings and one renovation. All of them had received the rating 'Excellent' according to BREEAM. One case was a high-rise in Japan which was assessed according to the CASBEE system. The examples showed that rating systems are used in real building projects, and they are also used to guide setting of objectives.

A brief study on scientific papers concerning sustainability in the steel construction sector was also made in order to see whether the research community is receiving inputs from the sector. It showed that evidence were provided through case studies in particular in environmental impacts.
In all LCA-based cases the following indicators are applied:

- Global Warming Potential;
- Destruction of the stratospheric ozone layer;
- Acidification potential of land and water resources;
- Eutrophication potential;
- Formation of the tropospheric ozone photochemical oxidants.

2.1.3 Study on integration of sustainability to performance-based design and building (T1.3)

A study based on a literature survey was conducted about approaches to assess both the technical quality and sustainability of a building project. Two fundamentally different approaches were identified that can be described as 'the Performance Approach' and 'the extended LCA'.

Performance approach in design and building

The performance based approach was defined by CIB (1982) as "a practice of thinking and working in terms of ends rather than means. It is concerned with what a building or a building product is required to do, and not with prescribing how it is to be constructed." Deru & Tortellini (2004) describes the approach with the following six steps:

1. Develop a vision statement for the building project to act as a guide for the design, construction, and operation of the building.
2. Divide the vision statement into topic and subtopic areas to address specific details.
3. Define objectives of the building project for each of the subtopic areas.
4. Establish clear and measurable goals (may be an iterative process).
5. Define performance metrics to measure the progress toward achieving the goals.
6. Develop and carry out a plan for monitoring the building performance throughout the design and operation of the building.

Implementation of performance-based approach in design practices induces a growing demand for new design tools and a new design approaches. These include e.g. tools for

- Implementation of standards in the fields of thermal and energy performance,
- Indoor air quality, structural engineering, fire safety
- Methodologies for optimal design accounting for risk and life cycle cost;
- Computerized design platforms for overall performance integrated CAD;
- Methodologies for the evaluation of building performance;
- Re-organization of the regulatory design approval process;
- Special design solutions/features geared toward energy conservation;
- Performance-based methodology for sustainable building design and environmental impact assessment;
- Implementation guidelines for various building occupancies;
- Integrated performance approach in the design for fire safety;
- Optimization of building evacuation through computer simulation;
- Use of renewable energy sources and energy systems;
- PBD of load bearing structures and their optimization; integrated structural design applying optimized design methods.

The Performance approach can be used whether the process is about an existing or new asset. It is applicable to the procurement of constructed assets and to any phase of the whole life cycle Building Process, such as strategic planning, asset management, briefing/programming, design and construction, operation and maintenance, management and use, renovations and alterations, codes, regulations and standards.

Performance analysis

A performance analysis is a process between identification of requirements of a building during its life-cycle and their presentation in various building designs. The user needs are in common expressed qualitatively, and their interpretation and organisation in technical, usability and economic terms is a necessary step (Figure 1).

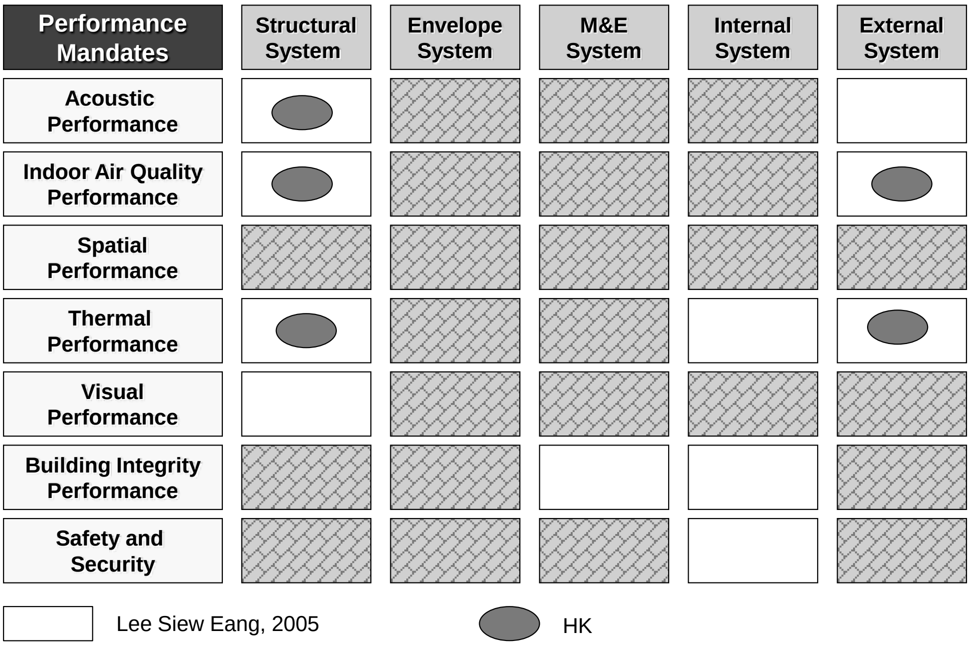


Figure 1. Performance issues related to technical solutions (based on Lee, Siew & Eang 2005)

The performance characteristics can be organised hierarchically. Through a hierarchy, a building concept can be qualitatively described and technical and/or economic target specifications established. Performance analysis may be used as an integrative platform for different experts to make common decisions. For different building concepts and projects, a generic model of hierarchical performance objectives can be developed, and used to systematically analyse the different goals. A pre-organised hierarchy becomes an advanced development and evaluation tool with concrete information and specific methods. For the management of the buildings performance, the value tree analysis offers a logical way to organize the various performance objectives, to evaluate their value and relations, to generate technical criteria and potential solutions and to incorporate rating and verification methods in the framework; this method was applied in the EcoProp tool of VTT, Finland.

Approaches to multi-criteria decision-making

A preliminary literature survey was conducted on Multi-Criteria Decision Making (MCDM) aiming at identification of methods used in relation to building design and sustainability. The body of literature is rich and growing concerning the generic methods but their application in selection of solutions in building design or construction is seldom investigated. More publications are dealing with the sustainability context.

The MCDM was described by Wong (1999) that “in essence, a MCDM problem is formed into hierarchy composed of four elements that are the goal, the objectives, the criteria and the alternatives. According to Turskas et al (2009), “multi-criteria decision-making methods intuition is closely related to the way humans have always been making decisions. Consequently, despite the diversity of multi-criteria decision-making approaches, methods and techniques, the basic ideas of multi-criteria decision-making methods are very simple: a finite or infinite set of actions (alternatives, solutions, courses of action ...), at least two criteria, and obviously, at least one decision-maker.” Ding (1999) describes MCDM as “a technique designed to value two or more criteria”. MCDM is a class of methods which is further divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM). The methodologies share common characteristics of conflict among criteria, incomparable units, and difficulties in selection of alternatives.

According to Wong (1999) a set of criteria is considered on a set of alternatives, in order to

- Determine the best alternative or a subset of best alternatives (choice problem – like selecting a design solution), or

- Rank alternatives from best to worst (ranking problem – like prioritizing maintenance projects), or
- Divide the set of alternatives into subsets according to some norms (sorting problem).

The best alternative is usually selected by making comparisons between alternatives with respect to each attribute. The multi-criteria decision process is as shown in Figure 2.

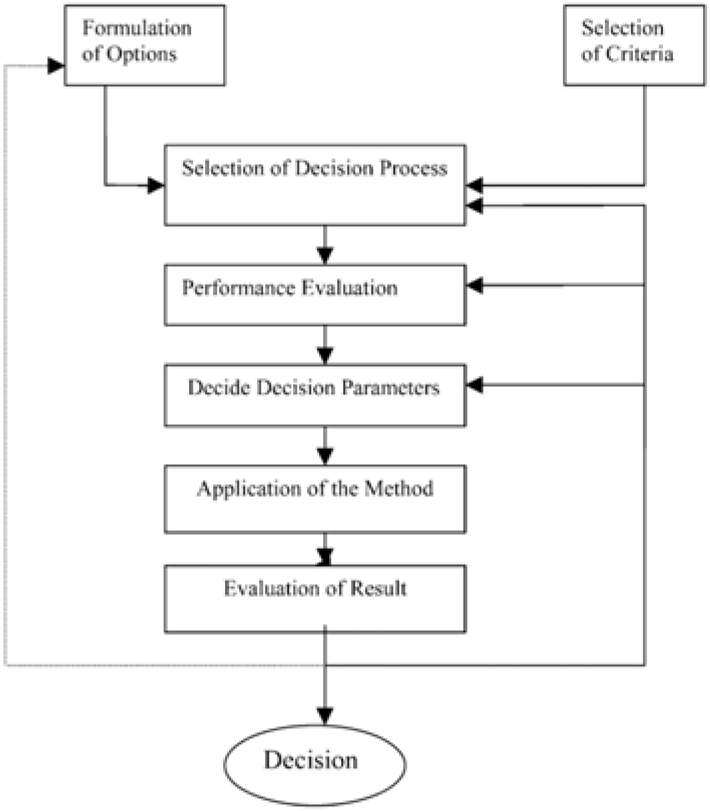


Figure 2. Decision-making methods in common (Pohekar & Ramachandran 2004).

MCDM in the framework of sustainability

The environmental and sustainability assessment methods and systems involves subjective valuing and aims at decision-making; thus knowledge about decision-making methods is fundamental for the development of the SB_Steel methodology and software; a preliminary study concerned identification of potential approaches that were further studied in the WP2 and WP4.

In a multi-criteria analysis the alternatives are compared against criteria. The method based on several individual criteria each one assessed separately has the advantage of transparency; however it makes the evaluation more complex. These methods assume that there exist a utility function U (or a value function) representing the decision making preferences (Guitouni and Martel 1998). In such a case, the task is to produce the function and then the ranking of alternatives is straightforward. It is also possible to aggregate some criteria which would make the interpretation easier but reduces transparency. Among the usual aggregation functions there's the Multi Attribute Utility Theory (MAUT) (Benoit and Rousseaux 2003).

Methods based on the outranking approach aim at the aggregation of the decision-making preferences established when comparing alternatives within each criterion (Benoit and Rousseaux, 2003). The outranking relation aSb (a outranks b) holds when there is a strong reason to believe that with respect to all the criteria, a is at least as good as b. By the use of thresholds, the outranking approach leads to different structures depending on the preference relations taken into account. Contrarily to the previous approach, this one allows for incomparability.

The aggregation of the alternatives evaluations implies some kind of "compensation ". There are no unanimous definitions to characterize the degree of compensation. However, according to Guitouni and Martel (1998) any MCDA method can be either:

- Compensatory – where an absolute compensation between different evaluations can exist. In this case, a good performance on one criterion can easily counterbalance a poor one on another;

- Non-compensatory – where no compensation is accepted between the different criteria. In this case, the criteria are considered to be important enough to refuse any kind of compensation or trade-offs;
- Partially compensatory – in this case, some kind of compensation is accepted between the different criteria.

All single criterion methods fall into the category of compensatory methods, whereas the outranking methods are much less compensatory than the former (Guitouni and Martel, 1998). Some authors (Benoit and Rousseaux, 2003; Benetto et al., 2008, Geldermann et al., 2000) argue that from the environmental point of view the compensation has to be avoided as much as possible, as a very serious environmental problem cannot be compensated by a less serious environmental problem. However, from a sustainable perspective when several dimensions are evaluated against each other, what is the degree of acceptable compensation?

Trade-offs or compensability plays an important role in the implementation of the concepts of strong and weak sustainability (Munda 2005). According to the concept of “strong sustainability”, the existing stock of natural capital must be maintained and enhanced because the functions it performs cannot be duplicated by manufactured capital. The rationale is that some values are irreplaceable and thus, no trade-offs are admissible. On the other hand, the alternative concept of “weak sustainability”, allows the replacement of natural capital by manufactured capital of equal value. Hence, the implementation of strong sustainability implies the use of non-compensatory multi-criterion algorithms (Munda 2005). Furthermore, according to Munda (2005), complete compensability is not desirable in a method for dealing with sustainability decision problems and, in the framework of social decisions, criteria weights may be used in the form of importance coefficients and not as trade-offs.

Hence, completely compensatory approaches should not be considered for the decision-making problem in the context of sustainability. However, it is considered that some kind of compensation is acceptable between different criteria.

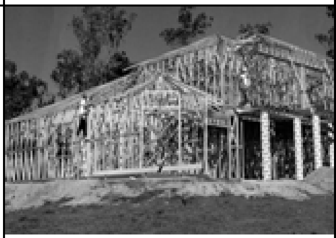
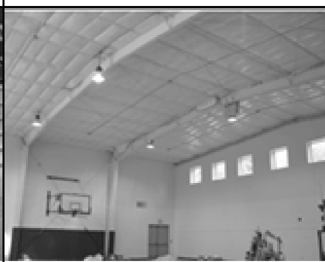
In the context of Life Cycle Environmental Assessment, different MCDA methods were compared according to the criteria of non-compensatory degree, sensitivity to thresholds, practicability and workability (Benoit and Rousseaux, 2003). The results of the analysis showed that there is not a single approach satisfying all the referred criteria and the choice of the MCDA approach depends on the characteristics of the analysis itself.

Typologies of steel-frames buildings with respect to sustainability

Typologies of steel-framed new buildings were studied in order to establish categories for typical macro-components. The process was based on integration of approaches in background literature and research reports such as European projects related to energy performance of buildings as well as documents of manufacturers of steel structures and steel-based components.

From the viewpoints of intended use of a building, buildings can be broadly classified into residential buildings and non-residential buildings. Taking into account the content of steel in a building and the size of the building, a classification matrix for steel building was proposed, as represented in Table 8.

Table 8. Building typology and different extents of steel-based solutions.

	Category 1	Category 2	Category 3
Single & multi-family building			
Apartment blocks			
Office buildings			
Commercial/ Industrial buildings			

Integrated pre-design

Integrated design teams and tools are repeatedly regarded as necessary in order to establish processes and practices that ensure more sustainable buildings. The issue of integrated design is closely related to performance based design as well in which sustainability is included as one essential aspect but could also be prioritized at top. The issue of integrated pre-design was studied through a literature survey to deepen the knowledge about the context in which the software tool to be developed might become helpful support for selection of solutions.

Integrated design is a procedure considering and optimizing the building as a system of systems including structures, spaces and technical equipment for the whole lifespan. This can be reached when all actors of the project cooperate across disciplines and agree on far-reaching decisions jointly from the beginning. The integrated design process emphasizes the iteration of design concepts early in the process. It is important for the early design phases that concepts are worked out together for all design issues: for example, the solutions for energy and building equipment are not designed complementary to the architectural design but as integral part of the building very early.

The integrated design process is not a new principle. What is new is that the knowledge and experience gained by an analytic consideration of design make it possible to formalize and structure the process and to incorporate it into design practice. The essential gains are as follows (Löhnert et al 2003):

- *Motivation and competence*: A qualified project starts with team members who are willing to achieve a high quality design, to provide a wide range of technical and communication abilities and to deviate from traditional practices.
- *Clear objectives*: Interdisciplinary teamwork is begun in the pre-project stage on the basis of a clear definition of goals and by applying different analytic and evaluative tools as needed.
- *Continuity of quality assurance*: Continuous examination of the design goals by a qualified design management takes into account any number of structural alterations and disruptions from the outside over the course of the entire design and building process and during the initial period of building operation.

The first step in the integrated process is developing the project brief by identifying the requirements of the building through consultation with stakeholders. This can be done through surveys or by holding a series of visioning workshops at which stakeholders can voice their opinions and have input into the design brief. A kick-off workshop should be held to develop the project goals and design requirements and to encourage a relationship among the team members. Following the kick-off workshop, a series of design workshops need to be held by the design team to develop an initial building concept or concepts for the project. An iterative process is required to develop the preliminary design so that it continues to meet all the project objectives.

Various workshop and requirement management tools can be used (e.g. EcoProp of VTT). The project goals need to be clear enough for the project team to develop a relevant design concept and solutions. All the principal design consultants should be involved in this stage. Preliminary design workshops should continue to develop the detail of the initial concept design. These workshops require team members to visualise and evaluate their design more clearly.

Methodology for analyzing and selecting the most appropriate strategies to improve energy efficiency and indoor environmental quality in new or existing buildings is based on elements of systems engineering, application of the concept of building quality and performance assessment. In the early stages of design this would allow for optimum scenario choice, able to meet the conflicting criteria whose satisfaction level can be established with the participation of all stakeholders (Draghici-Ovidius *et al.* 2010).

Taking into account all the aspects presented before, the team should take the project to the next level and start working on the detailed design-which means the drawing phase and afterwards the construction phase.

For the future, one foreseen direction is that the building information modelling technologies (BIM) will allow comparison of fully developed designs at earlier and earlier stages of a new building project thanks to stored specifications, still increasing capacity of computers and software to integrate different design software used by architects and special designers. At the moment, use of several design, decision-making and sustainability tools are needed in a sustainability-wise building project.

Data collection procedure for case-studies

The case study questionnaire was developed in order to establish a data base and to evaluate the level of performance for each main type of building (family houses, multi-storey buildings used for apartments, multi-storey building used as offices and industrial buildings).

The case study questionnaire was developed in order to follow the real steps that are used in an integrated design approach from an engineer point of view. From the location of the building (which can help us understand for example the level of performance used for acoustics –if the building is an intense circulated area or the need for special systems for ventilation if natural ventilation cannot be used in a big percentage due to the high quantity of outdoor dust) till the renovations that are needed or changing the space division or repurposing of the entire building.

The first question in the questionnaire was about the location of the building project because it can tell a lot regarding some structural design decisions. A developer wants a site for a building that would give the maximum land efficiency, structural safety, interior comfort and more importantly a short period of construction and minimum costs. The first problem that an architect or an engineer faces is how to explain to a developer what integrated design is and why it is better than an traditional approach and how this could improve his life or the efficiency of the workers (for an office building) but the most important problem how the initial costs for integrating the eco-friendly systems will reduce the maintenance costs (heating and cooling costs, electricity etc.).

The questionnaire was divided into several parts each of them covering some basic type of structure: houses, multi-storey office building/industrial building, and multi-storey apartment building. Four building project examples were chosen for a preliminary study about suitability of the template to cover essential issues of a sustainable building project and also to evaluate their fitness with the needs of the case-studies to be done in detail in WP5.

2.1.4 Proposals for approaches to requirements management in new build and renovation project (T1.4)

Task 1.4 summarized the wide variety of research issues in the other Tasks of the WP1 and proposed the list of key indicators to be investigated in the subsequent work packages.

Two types of indicators were proposed to be considered: core indicators and additional indicators. Core indicators were meant for both the conceptual stage and pre-design stage, whereas additional indicators were regarded more suitable in the latter stages (pre-design). The core indicators are presented in Table 9. In the Workshop, the social indicators were discussed and regarded as problematic for a decision-making aid due to missing data and metrics.

Table 9. Proposal of WP1 for core indicators suitable for concept and pre-design stages.

Environmental Indicators		
Environmental Impact	1	Global warming potential
	2	Depletion potential of the stratospheric ozone layer
	3	Acidification potential of land and water
	4	Eutrophication potential
	5	Formation potential of tropospheric ozone photochemical oxidants
	6	Abiotic Resource Depletion Potential for elements
	7	Abiotic Resource Depletion Potential of fossil fuels
Energy	8	Total Primary Energy Demand
Economic Indicators		
Life Cycle Costs	9	Construction costs
	10	Operation costs
	11	End-of-life costs

2.2 Concept of Sustainable Steel-Framed Building (WP2)

Work Package 2 comprised fundamental steps toward the decision-making platform for the early design stages of a steel-framed and steel-intensive new building. It was divided into four research tasks and the task to organise a Workshop and publish its Proceedings. WP2 produced one technical deliverable and the Milestone report 'Requirements and recommendations for the decision-making platform and software'.

2.2.1 Characterization of steel-framed buildings, in respect to basic building components and typical in-fill solutions (T2.1)

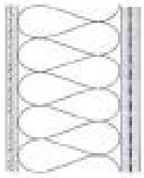
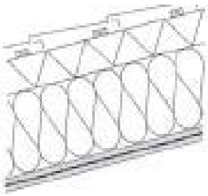
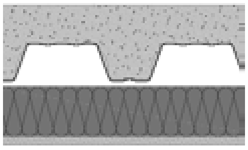
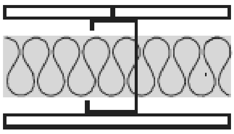
Task 2.1 established a basis to establish a databank of macro-components of steel-framed new buildings to be used in the decision-making platform. The identification of building components was conducted in four phases. At first, cold-formed, hot-rolled and steel-concrete composite structures were presented regarding the data needed for the sustainability assessment. Next, components and structures with steel and other materials such as thermal and acoustic insulation were specified, in a way that it would be possible to acknowledge steel intensive buildings performance regarding structural and fire safety, acoustic and thermal properties, among others (Table 10).

Table 10. Use of steel in building systems and related typical other materials.

Building system	Building elements	Materials
Structure	Columns Beams Floors (including roof) Lateral Bracing systems	Steel structure Concrete structure (Timber structure)
Façade system	Glazing Window frames Closed window area´s Thermal insulation material	Aluminium curtain wall-systems (Brick in external wall) Thickness 50–150 mm, alternative materials
Roofing structures	Trusses, beams, joists Waterproofing Thermal insulation Moisture barrier	Steel, bitumen roofing felt PUR, PIR, mineral wools Wood-based boards
Foundation	Not considered in Task	
Infill/ partitioning	Light weight partition systems Ceiling systems Floor screeds	Lightweight steel + plasterboard Lightweight clay fired brick
Services	Material impact were assumed at a fixed amount	
Circulation (stairs, elevators)	Material impact to be disregarded at this stage	

At last, the applicability of chosen components to represent best practices was tested through interviews of designers, contractors, suppliers and fabricators. The typology of steel buildings analyzed was a single story residential building and multi-story office building in three different climate zones. Table 11 presents an example of the different solutions identified and their properties.

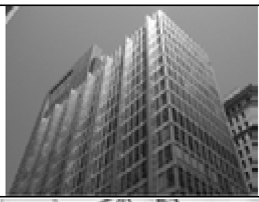
Table 11. Examples of typical steel-based building components identified.

Solution	Description	Thickness (mm)	Thermal conductivity (W / m·K)	Sound reduction (dB)	Fire Resistance (min)
External wall 	Rendering (reinforced, mineral) Plaster base Steel studs/mineral wool insulation Vapour barrier Double plasterboard (fire-proof)	≥ 200	0.096	*23–30 (Rw)*	30
Roof 	Roof covering, tile Roof battening Insulation (wooden fibre-board/XPS) Load-bearing pro-file/mineral wool insulation Vapour barrier Internal cladding: double gypsum plasterboard	≥ 345	0.072–0.101		≥ 30
Floor 	Reinforced concrete Trapezoidal steel sheet Mineral wool insulation Gypsum plasterboard	≥ 120 - ≥ 300	0.062–0.112[1]	51–72	30–120
Internal wall 	Gypsum plasterboard Metal studs/mineral wood insulation Gypsum plasterboard	75–150	0.545	34–62	30–120

2.2.2 Concept of environmental impact assessment based on macro-components (T2.2)

The macro-components were organised in a database according to the matrix proposed in WP1 but excluding the category 3 with minor use of steel-based solutions (see Table 12).

Table 12. Categories of steel-framed buildings in the SB_Steel database.

	Category 1 (C1)	**Category 2 (C2)**
Single & multi-family building (T1)		
Apartment blocks (T2)		
Office buildings (T3)		

The database was further divided into different macro-components, regarding their function in a building. In Figure 3, the structure of the data base is presented, according to the organization of the macro-components and their hierarchy. Note that all the macro-components are divided in terms of their structural role in the structure, i.e., load-bearing or non-load bearing.

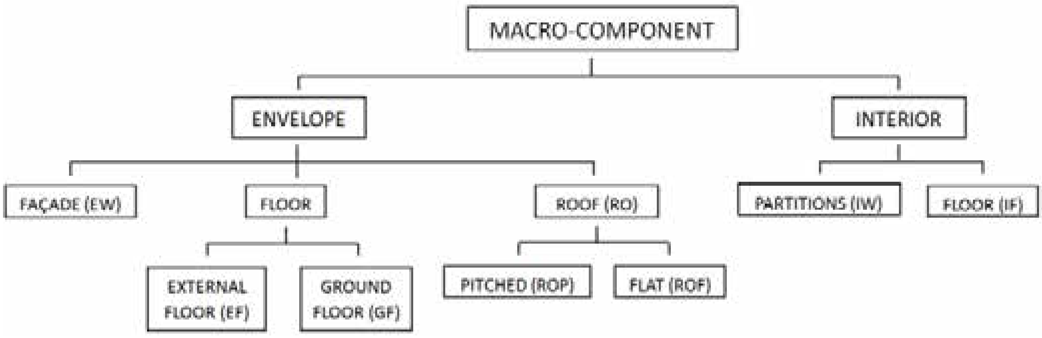


Figure 3. Hierarchy of macro-components.

The concepts presented in the European standard EN 15978:2011 – Sustainability of construction works – Assessment of environmental performance of buildings were adopted as the basis for preparing the data of macro-components. They comprised the following:

- *The name of the macro-component and its reference* – A code was given for each group of macro-components, creating a simplified terminology according to figure 1. The description of the macro-component incorporates its structural role in the building (external wall, partition, roof, load-bearing or non-load bearing, etc), the type and category of the building where it is more viable to be used and finally the number of the macro-component. – TypeBuildingCategory_MacroType_MacroNumber.

- *Functional equivalent* – It is defined as one square meter of a macro-component with the same function in the building (e.g. external wall, roof, ground-floor, etc.). The life cycle assessment is a cradle-to-cradle analysis, for the recyclable materials.

- *Geometric characteristics of the components* – The main geometric characteristic to be defined are the thicknesses of the different layers. Also, the latter is parameterized, influencing other parameters, such as the mass of each material and its thermal behaviour.

- *Characteristics of its thermal behaviour* – Thermal transmittance coefficient is presented in the macro-component layout. Taking in account that the macro-components are parameterized, mostly through the variation of the insulation thickness, it is necessary to calculate the U-value for each parameterization.

- *Reference study period (RSP)* – The RSP of the macro-component is the service life of the building, for example 50 years. This means that, if the macro-component's materials/products service life is lower than the RSP, it is necessary to account for maintenance/refurbishment scenarios.

- *Environmental profile* – The environmental profile accounts for the following impact categories: (i) global warming potential, (ii) depletion potential of the stratospheric ozone layer; (iii) acidification potential of land and water; (iv) eutrophication potential; (v) formation potential of tropospheric ozone photochemical oxidants; (vi) abiotic resource depletion potential for elements; and (vii) abiotic resource depletion potential for fuels, and the energy categories: (i) use of renewable primary energy (excluding energy resources used as raw material) (ii) use of non-renewable primary energy (excluding primary energy resources used as raw material).

- *Processes data source* – Since, an element of a macro-component is an assembly of several processes, it is crucial to defined which processes were used. Thus, a detailed information file was produced, where all processes codes (as defined in Ecoinvent database) used to completely define the element are presented.

Environmental profiles of macro-components

The international standards ISO 14040 and ISO 14044:2006 and the European standard EN 15978:2011 were adopted as the methodological basis for calculating and informing about environmental profiles of macro-components. The profiles make a major part of the macro-component data-base.

According to EN 15978:2011, the environmental assessment comprises four stages, plus a supplementary stage, which the standard defines as beyond the building life cycle. The four main stages are the Product stage (module A1–A3, according to EN15978:2011), Construction Process stage (module A4–A5), Use stage (module B1–B7) and End-of-life stage (module C1–C4). The scope of the Supplementary stage (module D) is the reuse, recovery and recycling potential of, in this case, the macro-components, which represent one of the primary advantages of the sustainable design (Figure 4).

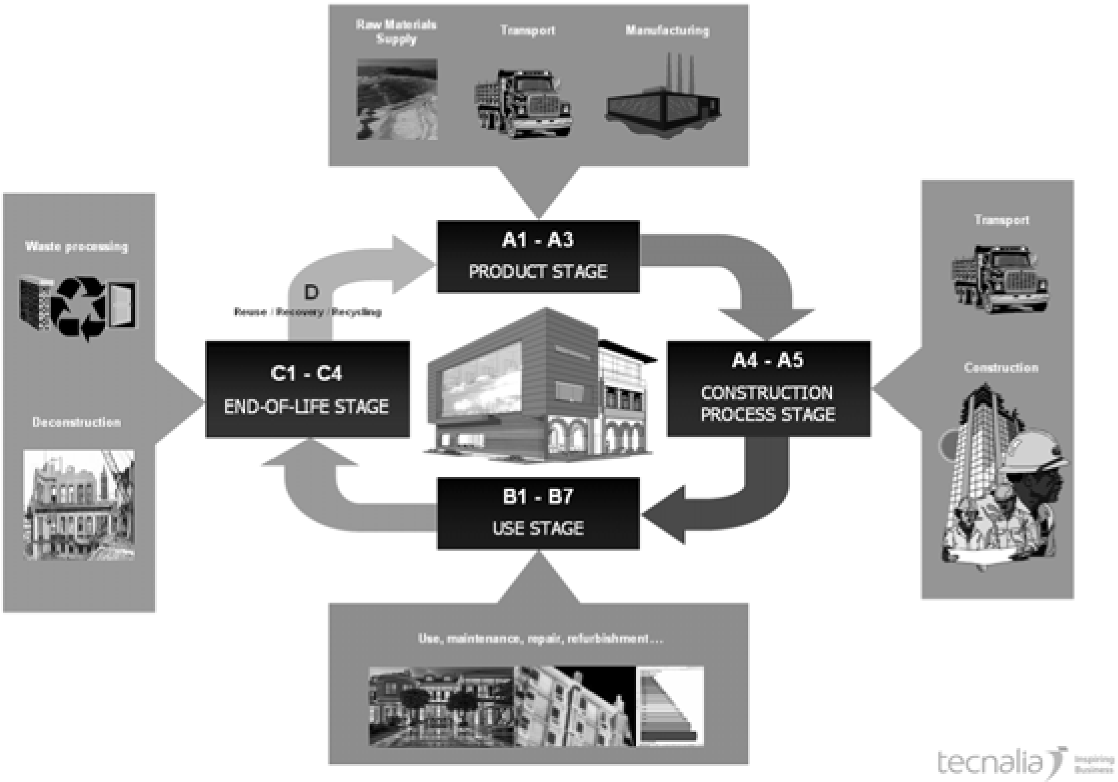


Figure 4. Life-cycle of a building from manufacture of construction products to the end-of-life (CEN standard EN 15978).

The Production Stage (modules A1–A3) regards the raw materials supply, their transportation to the plant and the manufacturing of the construction products/materials. This can be interpreted as a cradle-to-gate analysis. Manufacturing of capital goods (e.g. trucks, cranes and other equipment as such) are excluded of the analysis. Modules A4 to A5 (Construction stage) concern transportation of products/materials to a building site and the construction and installation processes.

In the LCA of the macro-components, the Use Phase (modules B1–B7) is destined to include environmental loads due to the normal functioning of the building. It should take in account possible renovations of the building in the RSP, since this period is not the same for some of the construction materials, thus being necessary to proceed to their replacing, maintenance, repair (e.g. walls paint, floor coverings) or even the refurbishment of the building (or part of it). Calculations include one renovation of the coverings in the building's life and the impact (emissions, energy and waste) associated. It is in this stage that operational energy use is quantified, as it was explained above. The End-of-life stage (modules C1–C4) is intended to analyse the impact of the final treatment given to the construction products that compose the macro-component, i.e., deconstruction/demolition, transport, waste processing and disposal. Detailed considerations regarding these aspects will be developed in the next paragraphs.

The life cycle inventory phase (LCI phase) of the LCA is intended to gather the input and output data of all system components being studied, regarding the goal and scope of the analysis. This will be achieved through "Ecoinvent" V2.2 database. The inventory is created through a set of processes that define the intricate network of raw materials, transportation, energy and waste that composes the assembly of a macro-component. As defined in ISO 14040, processes are a series of interrelated or interacting activities needed to transform inputs into outputs.

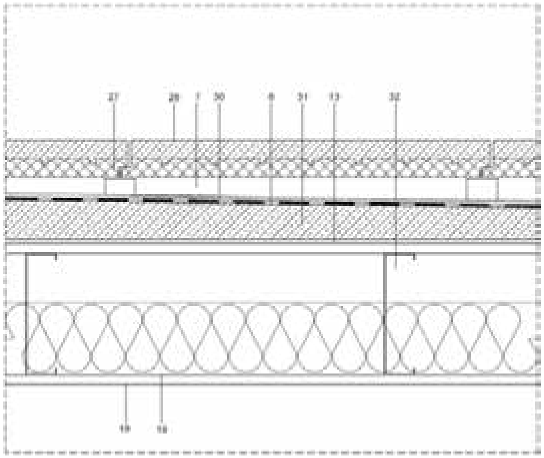
The third stage of the LCA is the life cycle impact assessment phase (LCIA phase), in which impact categories of the macro-component are quantified in all of the mentioned stages of the macro-component. Impact categories, are define in ISO 14040:2000 as the environmental issues of concern, which aggregate the emission and resources provided in the LCI.

The software applied in calculations of the LCI and LCIA is “SIMAPRO”, according, as stated before, to the “Ecoinvent” v2.2 database. The method used to calculate the environmental impacts is recommended by CEN, „CML 2 baseline 2000“ (CML 2001). For energy resources consumption the method was the „Cumulative Energy Demand“. The reason for choosing these methods was its recommendation by the European Normalization Committee and it has been used by the project beneficiaries with reliable results.

The final phase of the LCA is dedicated to the interpretation of the results provided in the LCI and LCIA and their inter-relations, thus, promoting the establishment of comparative studies between macro-components (for the particular interest of this project). An example of a macro-component sheet is presented in Figure 5.

Macrocomponent: *Terrace slab* **Ref. No.**: *MC_1*

Functional unit – 1 m^2



Components

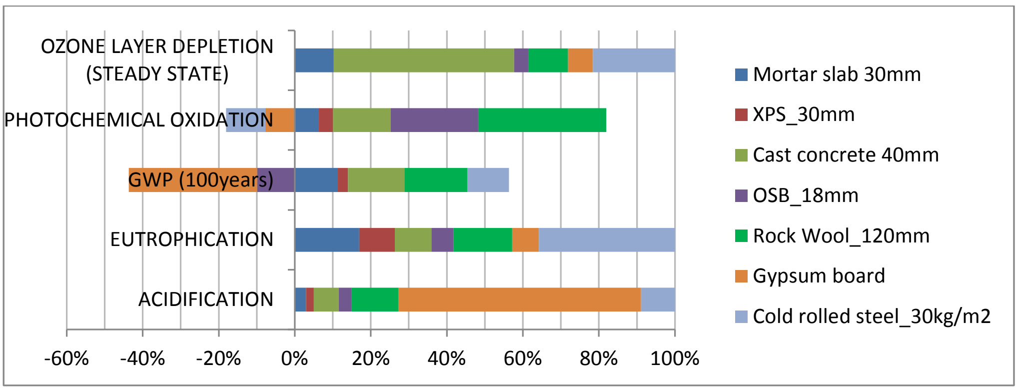
Ref.no.	Material	Thickness (mm)
27	Mortar slab	30
26	XPS slab	30
7	Air cavity	30
31	Cast concrete	40
13	OSB	18
32	Air cavity	80
15	Rock wool	120
19	Gypsum board	15
-	Steel	30 kN/m^2

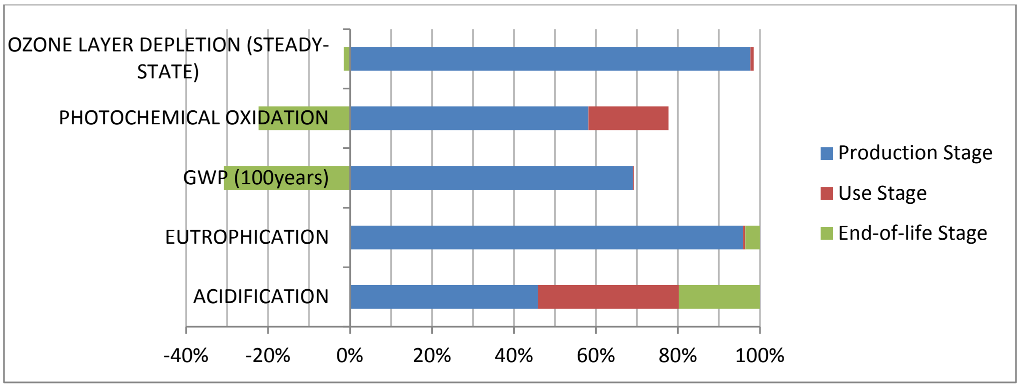
Thermal transmittances

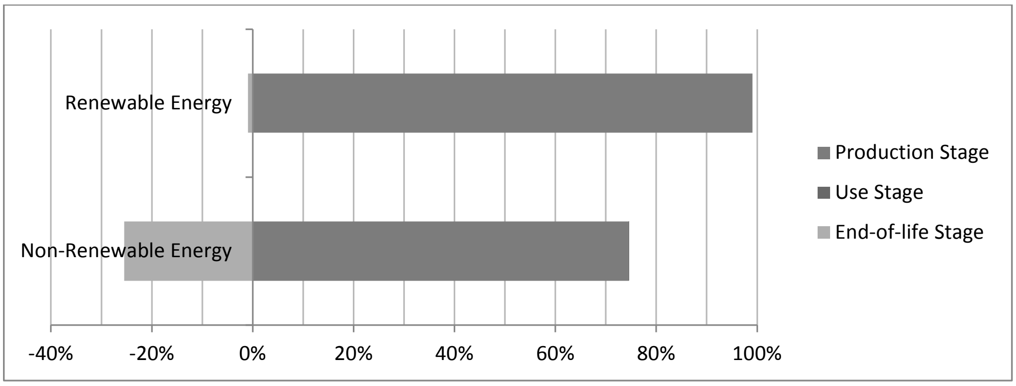
U (W/m2. °C)	$U_{bridging}$ (W/m2. °C)
0.212	0.373

Life Cycle Analysis: cradle-to-gate + end-of-life stage

	Unit	Production Stage	Use Stage	End-of-life Stage	Total
IMPACT CATEGORIES					
AC	kg SO2 eq	4,4E-01	3,3E-01	1,9E-01	9,6E-01
EU	kg PO4 eq	6,7E-02	3,3E-04	2,5E-03	6,9E-02
GWP (100years)	kg CO2 eq	9,1E+01	2,7E-01	-4,1E+01	5,1E+01
PhO	kg C2H4	3,9E-02	1,3E-02	-1,5E-02	3,7E-02
OD	kg CFC-11 eq	7,1E-06	5,4E-08	-1,1E-07	7,0E-06
ENERGY CATEGORIES					**Total**
Non-Renewable Energy	MJ	1,53E+03	3,53E-03	-5,25E+02	1,01E+03
Renewable Energy	MJ	2,92E+02	1,02E-05	-2,74E+00	2,89E+02







Description of the Component according to EN 15978	
COMPONENT:	**EPS**

Product Stage (A1-A3)		**Construction Process Stage (A4-A5)**	
CRADLE-TO-GATE		GATE-TO-BUILDING COMPLETION	
A1: Raw material supply		**A4: Transport**	
SOURCE:	Ecoinvent	SOURCE:	User Defined
Process identifier:	EIN_UNIT06567701677	Process identifier:	EIN_UNIT06567700533
A2: Transport		**A5: Construction - Instalation Process**	
SOURCE:	Ecoinvent	SOURCE:	User Defined
Process identifier:	EIN_UNIT06567701677	Process identifier:	EIN_UNIT06567700533
A3: Manufacturing			
SOURCE:	Ecoinvent		
Process identifier:	EIN_UNIT06567701677		
	EIN_UNIT06567701694		

Use Stage (B1-B5)	
BUILDING COMPLETION-TO-DEMOLITION/DISMANTLING	
B1: Use	**B4: Replacement**
SOURCE:	SOURCE:
Process identifier:	Process identifier:
B2: Maintenance	**B5: Refurbishment**
SOURCE:	SOURCE:
Process identifier:	Process identifier:
B3: Repair	
SOURCE:	
Process identifier:	

End-of-life Stage (C1-C4)			
C1: De-construction/Demolition		**C3: Waste Processing for Reuse, Recovery or Recycling**	
SOURCE:	User Defined	SOURCE:	-
Process identifier:	UD_C1_1	Process identifier:	-
	EIN_UNIT06567700536		
C2: Transport		**C4: Disposal**	
SOURCE:	User Defined	SOURCE:	Ecoinvent
Process identifier:	UD_C2_1	Process identifier:	EIN_UNIT06567702048
Subprocess identifier:	EIN_UNIT06567701774		

Benefits and Loads Beyond the System Boundary			
Reuse		**Recovery**	
SOURCE:	-	SOURCE:	-
Process identifier:		Process identifier:	
Recycle			
SOURCE:	-		
Process identifier:			

Figure 5. Example of a macro-component sheet (with codes used in the software).

Global energy consumption of a building

Energy consumption of a building during its life cycle was considered as a sum of the Embodied Energy and the Operational Energy. The first part regards the energy consumed in the entire supply and production chain of construction products from extraction of raw materials to the construction site. The energy used in transportation to a site and also the energy spent in the disposal (at this phase regarded as waste) should have been taken into account, but this data was not available in the databanks used for calculations.

Operational energy can be defined as the energy needed during the Use phase of a building for the comfort of the occupants. The current European regulation and national building codes were studied in detail in order to provide methods for case studies in WP5. The case studies were made according to national methods but a generic model was implemented in the software as explained in Chapter 3.2.3. The energy consumption depends on the climatic zones and a global map provided by Köppen-Geiger was adopted. However, the design conditions applied in case studies were in common according to national building codes.

Macro-components of envelopes are elements that separate the interior from the exterior environment. They have a major role in maintaining comfort temperatures and, consequently, a high impact on the energy consumption (energy demand). The data related to macro-components includes the thermal transmittance coefficient U which is usually calculated based on the data of product manufacturers according to standardized methods. It was concluded for the case studies that the prescribed U-values should be the starting point for the various macro-components but alternative compositions (especially thicknesses of insulation) needs to be calculated because the operational energy requirements can be fulfilled through improvements in structures or technical equipment (energy recovery) or space design.

Taking into account that the macro-components are parameterized, it is necessary to calculate the U-value for each parameterization. This will be achieved by calculating, through FEM software, the U-value of three or more thicknesses of the same macro-component and adjusting a curve to the calculated values, in order to get the curve’s equation. This equation will then be used to calculate the U-value of the macro-component parameterizations, given that the error is acceptable.

2.2.3 Assessment of whole-building performance and sustainability (T2.3)

This task studied relationships between various approaches to assess whole-building performance and sustainability. It also intended to identify the competitive aspects of steel-framed buildings.

Sustainable competitiveness of the steel construction sector

Competitiveness of the steel construction sector was studied in the recent sectoral reports produced by Ecorys to European Commission about steel manufacturing industry and about the construction sector including product manufacturers as well as documents of the European Steel Technology Platform ESTEP. The literature survey complemented the studies in WP1 concerning knowledge and know-how about sustainability in the steel construction sector.

The recommendations of Ecorys (2008) for the future of the steel industry were observed to have viewpoints of the sustainable development such as investments to cleaner and safer technologies, energy efficiency, green labelling. Ecorys defined the sustainable competitiveness in relation to the construction sector as the ability to achieve and maintain the (economic) competitiveness in accordance with sustainable development objectives (Ecorys 2011). It concerns both the contribution made by the construction sector to economic growth, social cohesion and employment and with those capabilities within the sector that enable it to compete in markets that are open to international competition.

Recommendations of Ecorys (2008, 2011) were recognized to be in line with the vision and strategic research agenda of the ESTEP. It was concluded that the steel construction sector should elaborate more solutions and services for building level taking into account different products and systems. This would mean "a beyond product by product approach": steel could offer 'holistic' economic solutions not only in the energy efficiency area but also for all other areas of sustainable construction. This is thanks to the benefits of steel such as for building,

- Steel is used in all technical systems of buildings, and thus the performance based design approach is easy to adopt;
- Steel can be used flexibly in light-weight and heavy-weight structures, and with all kinds of well-insulating materials;
- Steel structures can be demolished without major energy input;
- Steel-intensive solutions integrated with solar panels.

For building technologies:

- Steel construction is suitable and capable for rapid transform of the European building stock – new and renovation
- Steel structures facilitate the use of external insulation techniques which are favourable to the energy balance and allow the construction of buildings having a low inertia which reduces heating needs
- Ease of integration with renewable technologies for capturing, converting and storing energy
- More luminous spaces and efficient natural ventilation systems.

Construction Product Regulation and sustainability

The Construction Product Regulation (CPR) states essential requirements for a completed building but interpretation of generic objectives is made at product level. The environment and safety aspects relate mainly to the use of construction products throughout their life cycle and the dangerous substances used in their manufacture. Safety in construction and the free movement of services, engineering and construction services, are also an important policy priority, which is developed through the promotion of the Eurocodes and their implementation by the Member States. Compared with the preceding directive, the CPR includes a revision of the basic requirement —hygiene, health and environment for buildings and other construction works and the addition of a new basic requirement —sustainable use of natural resources as follows:

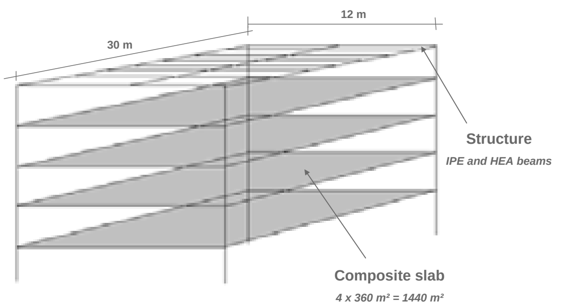
- Sustainable use of natural resources: The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:
    a) re-use or recyclability of the construction works, their materials and parts after demolition;
    b) durability of the construction works;
    c) use of environmentally compatible raw and secondary materials in the construction works.

Hierarchy of technical performance, sustainability and competitiveness

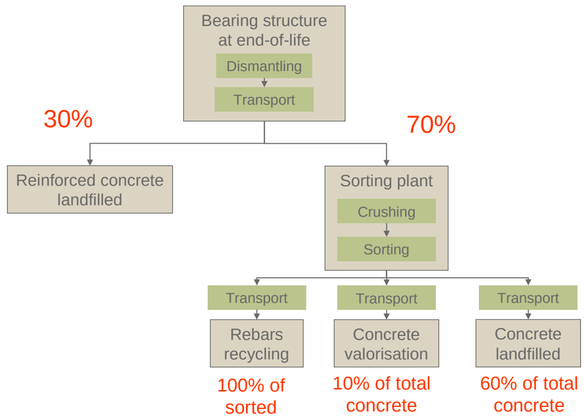
An LCA study was conducted in order to evaluate to which point environmental footprints illustrate the environmental performance of a building. The study allowed also a comparison between steel and concrete structures; aiming to prove the steel environmental competitiveness. The materials focused were: (i) reinforced concrete/masonry; (ii) hot rolled and cold formed steel sections and; (iii) composite steel-concrete elements. The functional unit was hence the load bearing structure. The target impact categories were Global Warming Potential (GWP) and Primary Energy Consumption (PEC), although Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Ozone creation Potential (POCP) and water indicator were also quantified.

The input data was the list of elements necessary to define the structure. From the description of the different parts of the studied bearing structure – bearing structure, slab and structural frame – the bill of materials was calculated. Data concerning steel was provided by the WorldSteel Association, originating from collection on sites between 2005 and 2007. Data related to the production of concrete and its components dates from 2001 and was provided by Ecoinvent. The cement content required for this type of application is 350 kg/m3 of concrete. A sensitivity analysis of the influence of cement content on the environmental profile of the building was also performed.

The case study was defined as follows: a four floors building, supporting an additional dead load of 1 kN/m² and an imposed load of 3.5 kN/m². Dimensions were 12m width for 30m depth. The mass balance is dominated by the concrete part of the composite slab (83%), since concrete is used for slab, which generally represents the largest part of the structural weight (Figure 6).



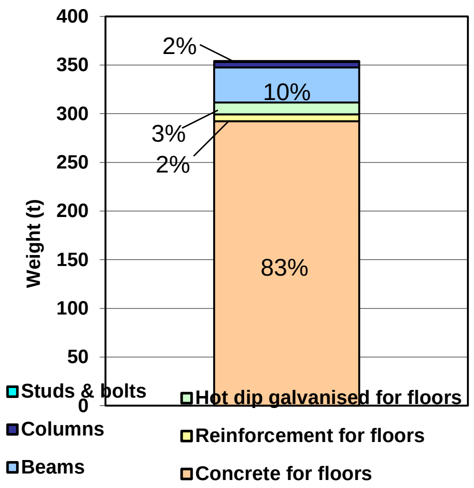
(a)



(b)

Element	Steel building Type	Quantity (t)
Structure		
Main beams	IPE A 330	10,320
Secondary Beams	IPE A 330	22,704
Edge beam	IPE A 270	2,947
Columns	HE 260 AA	3,895
Edge Columns	HE 180 A	1,704
Shear studs	d19 x 100 mm	1,109
Angles	Sections	0,863
Bolts	Rebars	0,189
Total structure		*43,731*
Floors		
Decking	Cofraplus 60	12,283
Concrete	Concrete (350kg cement per m3)	293,760
Reinforcement	Rebars	1,038
Mesh	Rebars	5,904
Total floors		*312,985*
Total building		356,716

(c)



(d)

Figure 6. (a) Case-Study to develop a simplified approach; (b) End of life scenario for reinforced; Concrete; (c) Bill of materials for the steel building; (d) Mass balance of the building.

The results for the whole building performance assessment are presented in Figure 7a) and 7b) GWP and PEC, respectively.

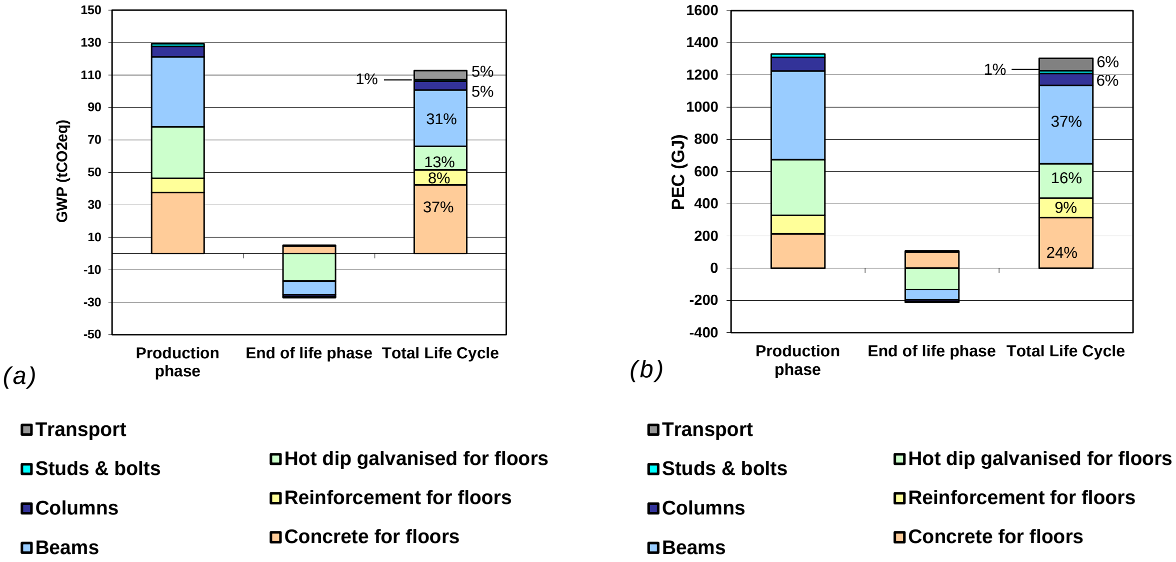


Figure 7. (a) Distribution of GWP; (b) Distribution of PEC.

Compared to the production phase, the contribution of steel is reduced, e.g. the GWP of steel elements during the production phase represents 71% of the total impact, compared to 58% for the entire life cycle. This enlightens the importance of integration of end-of-life aspects in environmental evaluations. Transportation of materials for the structural parts of a building also has a non-negligible impact on both GWP and PEC, confirming that it has to be taken on board for such evaluation. It may however be sensitive to the hypotheses made (distance. mean) and is therefore tested through sensitivity analysis. The detailed analysis of this case study highlights the importance of some parameters: the bill of quantity, material choice, steel grade and recycling rate are key parameters of the methodology.

The repartition of materials contribution is very similar between global warming potential and the other impacts categories: AP, EC, and POCP. Energy behaves a bit differently, due to the concrete material. This is therefore necessary to keep this indicator. Water consumption is not a classical LCA impact category, but an indicator. As expected, the concrete material is the material contributing the most to this indicator (63%). So, as far as LCA impact categories are concerned, the GWP impact is a good indicator of the environmental performance of the structure.

To complete the conclusions drawn from the case study first analysis, this application was analysed further through sensitivity analysis. The variation of the total GWP and PEC impacts is rather low: respectively, a reduction of 4% and 5% and an increase of 6% and 4% are observed. This demonstrates that very heterogeneous scenarios for the end-of-life of reinforced concrete have an influence but do not alter drastically the GWP and PEC results. The sensitive analysis confirms the hypotheses made for the calculation method, and the parameters that may influence the results:

- Transformation has a very low impact and can be neglected;
- Transportation impact is not negligible, but generic assumption (as the European transportation average) can be used without altering much the results;
- Cement content can have an influence on the environmental profiles calculated, thus have to be carefully chosen depending on the application;
- End-of-life of reinforced concrete has an influence on the results, in particular on the impact of reinforcement end-of-life. Scenarios of EOL have to be chosen depending on the application.

2.2.4 Model for decision-making in early stages of a building project (T2.4)

Task 2.4 developed the methods for the decision-making model to be incorporated to the tool that would support decision-making in regards to sustainability objectives. The goal of the tool was to evaluate the sustainability of different building solutions in two distinct stages of the project – conceptual stage and pre-design stage – with two different approaches; one that is simplified, addressing just few parameters and a more comprehensive one, which encompasses several more sustainability indicators. To corroborate with this idea, two groups of indicators were settled down: core indicators and additional indicators. Initially, core indicators proposed in WP1 consisted of environmental impacts and costs, and in an estimation of the operational energy demand. The additional indicators included the social indicators. Both can be regarded as important to be handled in establishing of a sustainable building project but the software development would need commonly approved and standardized methods.

The research made in the project showed that costs vary greatly from country to country, especially operational costs. This later would input several constrains and variables to the assessment method, requiring more data from users, which would contradict the main objectives of the tool: to be simple and easy to use. In what regards social aspects, no exact assessment models are standardized by now. In this sense, social aspects should be incorporated when more accurate standard methods are available. For these reasons, cost and social indicators were agreed to be excluded from the case studies and the software. The indicators which were really included in the case studies and tool, both for conceptual and preliminary design phases are the ones presented in Table 13.

Table 13. Indicators included in the SB_Steel methodology; for both conceptual and preliminary design phases.

Environmental impact categories	Unit	Energy related indicators (kWh/Year)
Global warming potential	Kg CO_2 eq	Heat transfer (heating and cooling season)
Depletion potential of the stratospheric ozone layer	Kg CFC11 eq	Heat Gains (heating and cooling season)
Acidification potential of land and water	Kg SO_2 eq	Energy needs for heating
Eutrophication potential	Kg $(PO_4)^{-3}$ eq	Energy needs for cooling
Formation potential of tropospheric ozone photochemical oxidants	Kg C_2H_4 eq	Energy needs for DHW
Abiotic resource depletion potential for elements	Kg Sb eq	Delivered Energy (for heating, cooling, DWH, total)
Abiotic resource depletion potential for fuels	MJ	Renewable Energy (for heating, cooling, DWH, total)
		Primary energy (for heating, cooling, DWH, total)
		Building's total energy needs

Two different algorithms were developed in order to address both stages of design. As said before, at first social and economic performance were foreseen to be part of the methodology (Figure 8).

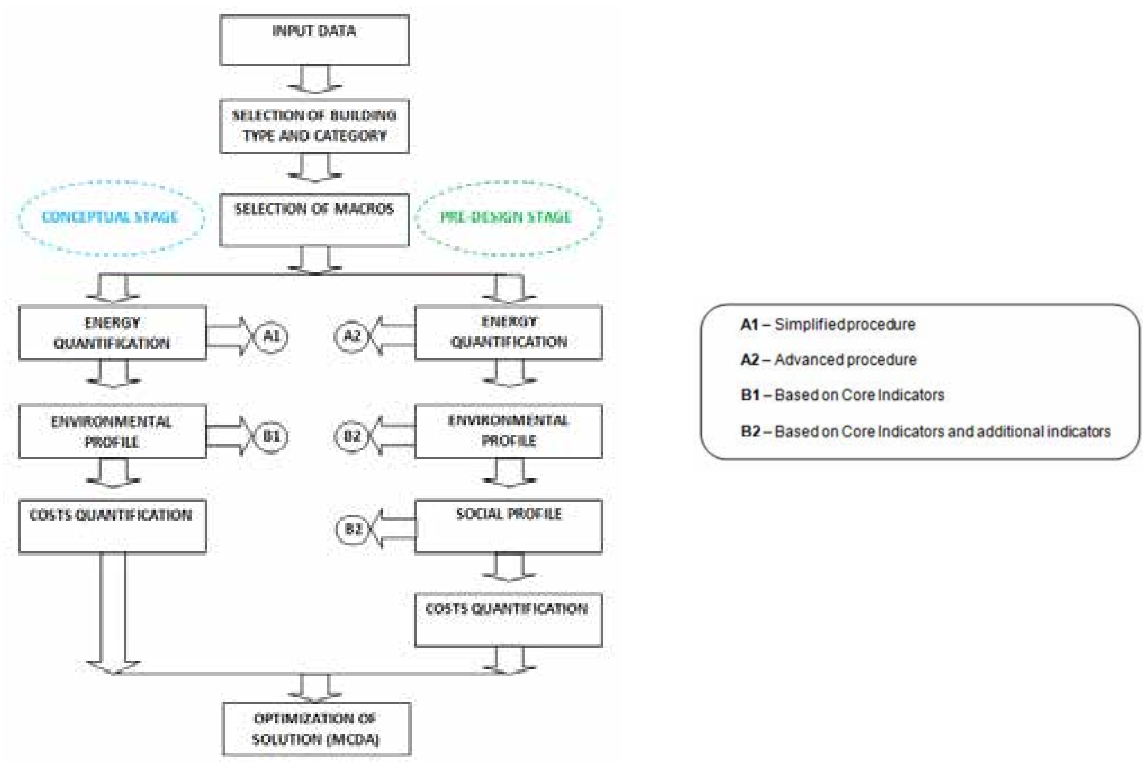


Figure 8. Initially planned framework for the framework of the assessment.

However, the software structure was further elaborated in WP4, and some changes were still regarded as necessary. The first stages and the final of the algorithm are common to both routes (design phases): input of data, selection of the building type and category, selection of the climatic zone in which the building is located and selection of the macro-components from the database. The energy quantification and the environmental impact assessment have different algorithms according to the design stage during which the assessment is performed.

From this, the methodology schematically described by Figure 9 was foreseen to be the best to be applied to the tool. The tool should be divided in three main phases: i) input; ii) engine and; iii) output.

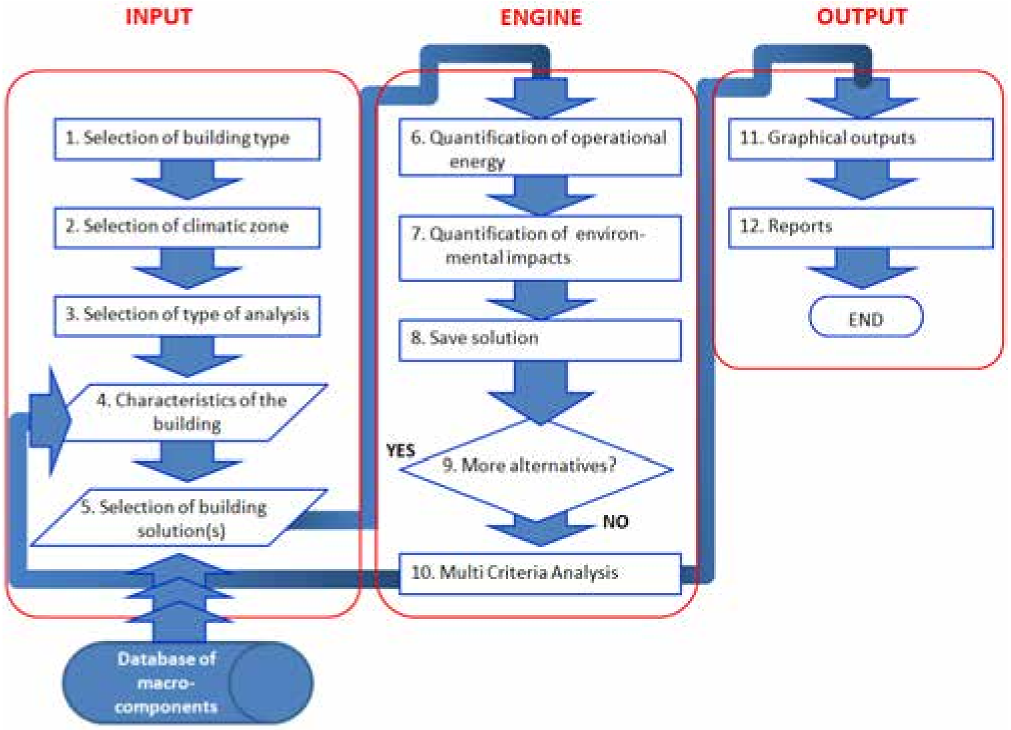


Figure 9. Methodology to be applied in the SB_Steel tool.

It was intended that users could easily assess the sustainability of their possible construction solutions. For that, the input data step, as well as the whole process, should be simple, and doable in a few minutes. Here the user should be able to add the data regarding the building typology, location (climatic zone), select the type of analysis to be performed, characterize the building geometry and select the macro-components to be assessed (Table 14).

Table 14. Data required in the input phase.

General Information	***Procedure for the data base***
Building typology	
Building type	*Select from the list (single family, office...)*
Type of project	*Select from the list (low, medium or high rise)*
Location	
County	*Select from a list*
Climatic zone	*Select the Köppen-Geiger climatic regions from a list*
Type of analysis	
Stage of the analysis	*Select if it is during “conceptual stage” or “ Pre-design stage”*
Scope of the analysis	*Select if it is a “Cradle-to-gate analysis”, “Cradle-to-gate + end-of-life recycling”; “whole life-cycle”*
Lifespan of the analysis	*Introduce the number of years to be considered*
Characteristics of the Building	
Size of the plot	*Total area of the site (m^2)*
Maximum liquid utilization index	*Maximum area or land percentage legally available for construction*
*Total area of building	*Estimation of the total area of the building (m2)*
Number of floors	*specific value ,estimated*
Height of the building	*specific value ,estimated (m)*
Length of the building	*specific value ,estimated (m)*

General Information	*Procedure for the data base*
Width of the building	*specific value ,estimated (m)*
*Area of each floors	*specific value ,estimated*
Number of storeys	*specific value ,estimated,*
*Area of the roof	*specific value ,estimated (m^2)*
*Area of the external walls	*specific value ,estimated (m^2)of facing north, east, south and west glazing;*
*Area of the internal walls	*specific value ,estimated (m^2)*
*Area of ground floor	*specific value ,estimated (m^2)*
*Area of internal slabs	*specific value ,estimated (m^2)*
Building orientation	*Specify the orientation of the main façade*
Budget available/investment cost	*Estimated cost (€)*
Heating equipment efficiency	*Default or Select from the list*
DHW equipment efficiency	*Default or Select from the list*
External wall absorption coefficient	*Default or Select from the list*
U-value of glazing areas	*Default or Select from the list*
Shading – solar transmission of glazing are-as	*Default or Select from the list*
Thermal properties of the ground	*Default or Select from the list*
Heat flow rate	*Automatic fulfilment, depending on the selected building typology*
Heating need for hot water	*Automatic fulfilment, depending on the selected building typology*
Presence time per day	*Automatic fulfilment, depending on the selected building typology*
Materials	
Macro-components	*Select from the list (database)*
*Bill of materials	*Add quantities of specific materials*

After that the assessment should start – engine phase. This phase should not be visible for users but represents a major part in the methodology – the quantification part. Here the procedures adopted shall depend on the type of analysis selected and on the design stage. According to what was defined by the users in the input phase, two different algorithms should be implemented, in order to address the availability of data in the conceptual stage and in the pre-design stage. In the conceptual stage the quantification of environmental criteria and energy requirements is based on simplified procedures, while in the pre-design stage, more complex procedures will be adopted. Moreover, in this stage the quantification of social criteria is also introduced, as proposed by the categorisation of the key indicators (core & additional criteria). Only after that the comparison and raking between alternatives shall be made.

The output part represents the section where the tool presents the results of the assessment to the users. It should present the results in two ways: graphical representation and reports. Using a graphical representation the users should be able to select the indicators they want to review and compare. The reports could be saved and/or printed so the users could keep the information with the project documentation.

Environmental performance calculation

The process to obtain the environmental profile of the alternatives (construction solutions) inserted by the users should be based in the same principles as the ones presented for the LCA of the macro-components, already presented. In fact, this latter are the base for the building's total environmental profile. The quantification of potential impacts of a building should be based on the modular concept of the recent CEN standards – EN 15978:2011 and EN 15804:2011 – developing scenarios (when required) for some of following life cycle phases/modules:

- A1:A3 – Product stage;
- A4:A5 – Construction process stage;
- B1:B7 – Use stage;
- C1:C4 – End of life stage;
- D – Benefits and loads beyond the system boundary.

When scenarios are needed, these should be transparently and objectively described and settled down, as presented in Figure 10.

PRODUCT STAGE
MODULES A1:A3

		Scenario
A1 + A2 + A3	Raw Materal Supply	According to materials individual information files: i) Gypsum plasterboard ii) Rockwool iii) Cold rolled steel profiles iv) Paint
	Transport	
	Manufacturing	

CONSTRUCTION PROCESS STAGE
MODULES A4:A5

			Scenario
A4	Transport	Type	3,5 - 16 ton Truck
		Distance (km)	50
		Fuel type	Diesel
		Additional information	-
A2	Construction - Instalation	Process	Mannualy installed
		Ancillary materials	
		Equipment	Manual and electrical tools
		Energy (MJ)	

USE STAGE - BUILDING FABRIC
MODULES B1:B5

			Scenario
B1	Use	Process (source,code)	NA
		Indoor Air	NA
		Soil and Water	NA
		Net potable water (m3)	NA
B2	Maintenance	Maintenance process (source,code)	NA
		Maintenance cycle (per year)	NA
		Net potable water (l/year)	NA
		Ancillary materials	NA
B3	Repair	Description	Repainting walls
		Repair cycle (per RSL)	1 (Repaint 50% of the outside surface)
		Wastage material (kg)	NA
		Ancillary materials	NA
		Equipment used	Manual tools
B4	Replacement	Replacement cycle (per RSL)	1 (Repaint 100% interior surface)
		Wastage material (kg)	NA
		Ancillary materials	NA
		Equipment used	Manual tools
B5	Refurbishment	Refurbishment cycle(perRSL)	NA
		Material input (kg/cycle)	NA
		Wastage material (kg)	NA
		Further assumptions	NA

END-OF-LIFE STAGE
MODULES C1:C4

			Scenario
C1 +	De-construction/ demolition		De-construction of each element of the macrocomponent with manual anc electric tools (srewer)
	Transport	Type	Truck 3,5-16ton.
		Distance (km)	50 or 50 + 15
		Fuel type	Diesel
		Additional information	
	Waste Processing	Processes	According to materials information
		Preparatory works	
		Wastage material added (kg)	
		Ancillary materials	
	Disposal	Processes	According to materials information
		Waste type (75/442/EEC)	17 08 02 (Gypsum-based materials)
			17 06 04 (Other isulation materials)
			17 04 05 (Iron and steel)
			08 01 14 (wastes from paint)
		Recycling potentials	Steel scrap is 100% recyclable
		Wastage material added (kg)	
		Ancillary materials	

Figure 10. Example of the scenarios' description.

Basics of the Energy Module to the tool

The energy related indicators were incorporated to the software based on theoretical studies on several parameters influencing the total energy demand and energy-efficiency. The methodology to assess the energy-efficiency at early design stages required the adoption of simplifying assumptions concerning the building shape, the structural system to be adopted, the building envelope and the interior finishes. The internal and external components of the building were selected from the database of macro-components. The macro-components enable the automatic calculation of required thermal properties, such as the U-value and the heat capacity.

The tool for energy calculation was developed in agreement with relevant European and International standards. This tool enables to calculate energy needs on a monthly basis for: (i) heating mode; (ii) cooling mode; and (iii) domestic hot water DHW production. In order to determine the contribution of each term involved in the thermal calculations it is necessary to rely on several standards, as shown in Figure 11.

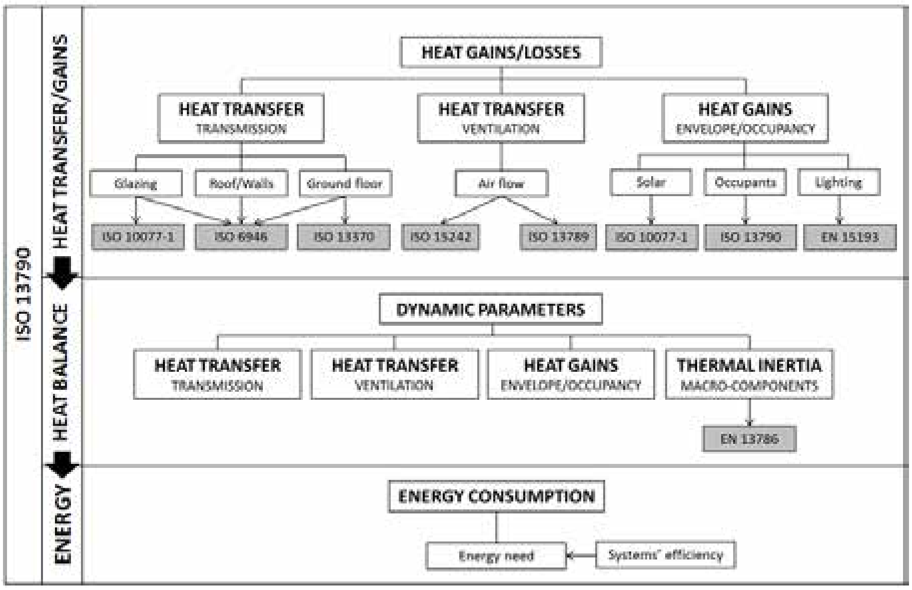


Figure 11. Flowchart of the algorithm for energy module and the reference standards for space conditioning.

ISO 13790 (2008) was selected as the base standard, which refers to specific calculations in other standards. The importance of the DHW production in the building's energy consumption was addressed in accord with the guidance of EN 15316-3-1 (2007). In national building codes, procedures may also be given for simplified approaches but for the software the common basis was regarded as more reasonable.

The prediction of the energy demand for space heating and cooling was undertaken by using a monthly quasi-steady-state approach, which relies in gains utilization factors to simulate dynamic effects. Additional parameters essential for the method were calculated in separate modules (sub-modules). Moreover, the energy for DHW production was also quantified in an independent module. The procedure and architecture of the algorithm used to determine these energy needs are presented in Figure 12.

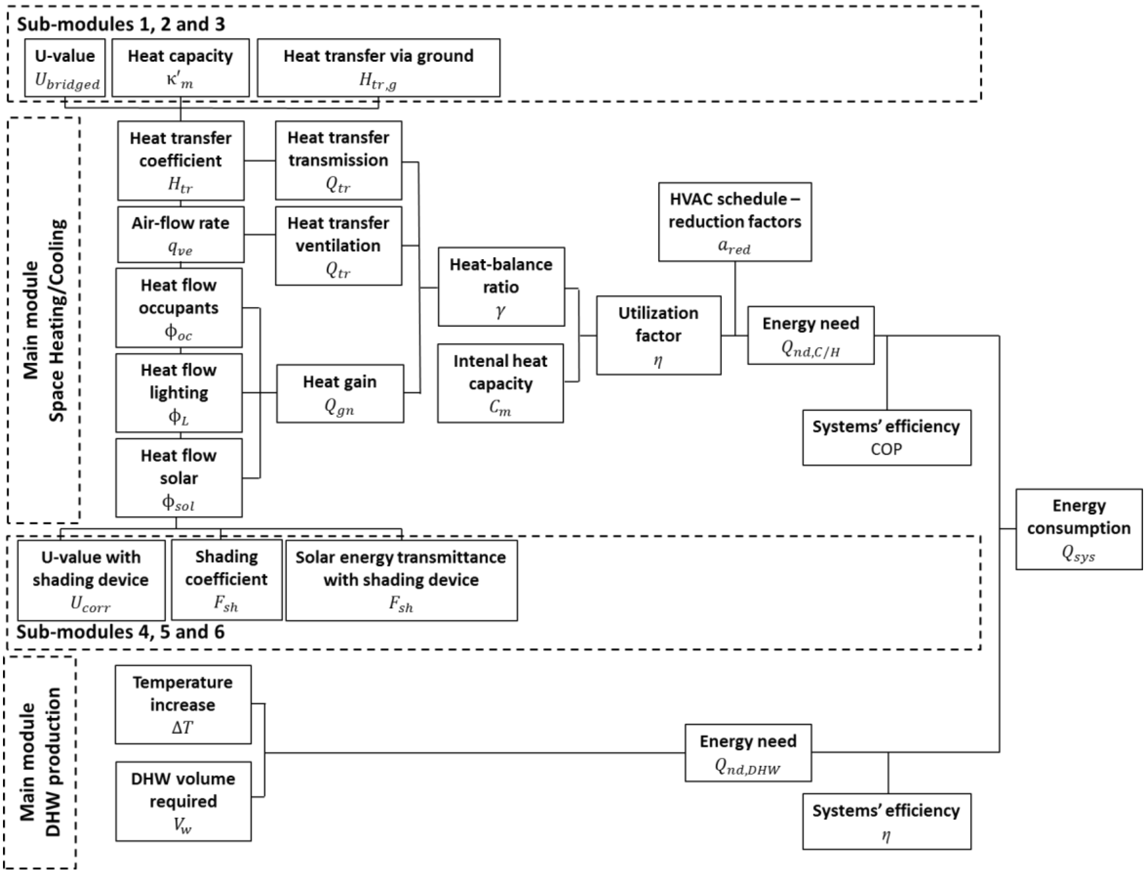


Figure 12. Flowchart of the calculation of the energy consumption of the building.

The sub-modules 1 and 2, corresponding, respectively, to the U-value and heat capacity of the envelope elements, are calculated for the macro-components selected by the user. The U-value of bridged elements (e.g. originated by the steel studs) is calculated in accordance with the method developed in ISO 6946 (2007) and improved by Gorgolewski (2007). Sub-module 3 covers the heat transfer via the ground. Sub-modules 4, 5 and 6 address the sub-routines used to calculate the effects of the shading devices and shading by external obstacles.

Expressions (1) and (2) are the primary main equations defined in ISO 13790 (2008) to determine the energy need (follow Figure for nomenclature):

$$Q_{H,nd,cont,m} = (Q_{H,tr,m} + Q_{H,ve,m}) - \eta_{H,gn,m} \cdot Q_{H,gn,m} \quad (1)$$

$$Q_{C,nd,cont,m} = Q_{C,gn,m} - \eta_{C,ls,m} \cdot (Q_{C,tr,m} + Q_{C,ve,m}) \quad (2)$$

where subscripts H and C denote heating and cooling modes, respectively, and *m* denotes monthly. $\eta_{H,gn,m}$ and $\eta_{C,ls,m}$, are the monthly utilization factors used in the heating and cooling modes, respectively.

For the heating mode, the utilization factor, $\eta_{H,gn,m}$, is given by the following equations:

If $\gamma_H > 0$ and $\gamma_H \neq 1$, then: $$\eta_{H,gn} = \frac{1-\gamma_H^{aH}}{1-\gamma_H^{aH+1}} \quad (3)$$

If $\gamma_H = 1$, then: $$\eta_{H,gn} = \frac{a_H}{a_H+1} \quad (4)$$

If $\gamma_H < 0$, then: $$\eta_{H,gn} = \frac{1}{\gamma_H} \quad (5)$$

where $\gamma_H = Q_{H,gn}/Q_{H,ht}$ is the heat-balance ratio; $a_H = a_{H,0} + \tau/\tau_{H,0}$ is a dimensionless parameter; $\tau = C_m/H$ is the time constant of the building zone and takes into account the thermal inertia of the building and the heat transfer by transmission and ventilation; $a_{H,0}$ and $\tau_{H,0}$ are dimensionless parameters, which take the value of 1 and 15, respectively.

The monthly utilization factor for the cooling mode is obtained through one of the following formula:

If $\gamma_C > 0$ and $\gamma_C \neq 1$, then: $$\eta_{C,ls} = \frac{1-\gamma_C^{-aC}}{1-\gamma_C^{-(aC+1)}} \quad (6)$$

If $\gamma_C = 1$, then: $$\eta_{C,ls} = \frac{a_C}{a_C+1} \quad (7)$$

If $\gamma_C < 0$, then: $$\eta_{C,ls} = 1 \quad (8)$$

The parameters used to obtain the utilization factors are similar to the ones presented for the heating mode, but with the values correspondent to the cooling mode (the dimensionless parameters $a_{C,0}$ and $\tau_{C,0}$ are also taken as 1 and 15, respectively).

When the HVAC systems operate on a schedule (i.e. in intermittent mode), ISO 13790 (2008) provides guidance to determine a reduced energy needs based on the calculations for the continuous mode, as follows:

$$Q_{H,nd,interm,m} = f_{H,m} a_{H,red} \cdot Q_{H,nd,cont,m} \quad (9)$$
$$Q_{C,nd,interm,m} = f_{C,m} \cdot a_{C,red} \cdot Q_{C,nd,cont,m} \quad (10)$$

The building time constant and heat-balance ratio also influence the reduction factor of the energy needs due to the intermittent operation of the HVAC systems, as observed in equation (11) and (12).

$$a_{H,red} = 1 - b_{H,red}.\frac{\tau_{H,0}}{\tau}.\gamma_H.(1 - f_{H,hr})\text{ , with } f_{H,hr} \leq a_{H,red} \leq 1{,}0 \quad (11)$$

$$a_{C,red} = 1 - b_{C,red}.\frac{\tau_{C,0}}{\tau}.\gamma_C.(1 - f_{C,day})\text{ , with } f_{C,hr} \leq a_{C,red} \leq 1{,}0 \quad (12)$$

where b_{red} is a fixed parameter, taken as 3 (both for heating and cooling modes); $f_{H,hr}$ is the fraction of the number of hours in which the systems are operating; $f_{C,day}$, represents the fraction of the number of days in the week, with the systems in operation.

The energy needed for DHW production is calculated following EN 15316-3-1 (2007). It is influenced by the type of building, its floor area and the temperature difference between the inlet water and the one desired at the tapping point, according to expression (13):

$$Q_{DHW,nd} = 4{,}182.V_W.(\theta_{W,t} - \theta_{W,0}) \quad (13)$$

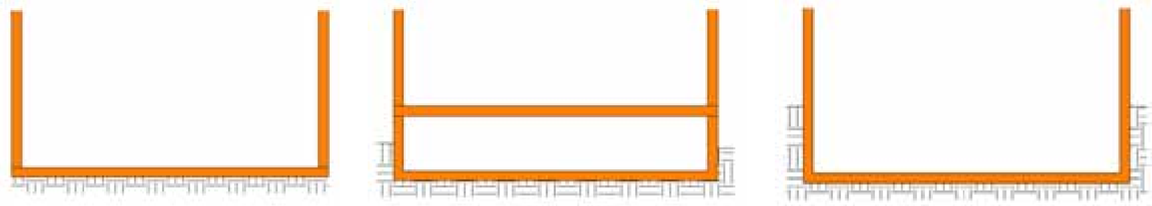
where V_W is the monthly DHW volume need as prescribed in EN 15316-3-1 (2007); $\theta_{W,t}$ is the temperature of DHW at tapping point [°C]; $\theta_{W,O}$, temperature of the inlet water [°C].

The tool was prepared to deal with the most influencing variables related with thermal behaviour and energy efficiency of the building. To address this, the main features of the tool are presented in the following paragraphs:

- Two major climate parameters must be defined in order to undertake an energy need calculation: i) air temperature; and ii) solar radiation on a surface with a given orientation. The methodology is currently calibrated for five climatic regions (classified according with the Köppen-Geiger climate classification, see Figure 3): (i) Csa; (ii) Csb; (iii) Cfb; (iv) Dfb; (v) Dfc. For each climatic region, data for various locations is provided, although the user may add user-defined values for specific locations.
- The building geometry and orientation are important factors in the energy calculation. In fact, the assessment of the effect of shading by external obstructions (overhangs and the geometry of the building itself) can result in energy savings. Since the solar data depends on the latitude of the location, several tables of shading coefficients were produced for different latitudes. The shading coefficients were obtained for all types of external obstructions (ISO 13790, 2008): (i) overhangs; (ii) fins; (iii) obstructions from the horizon. The tool allows to rotate the façades through the four main orientations (North, South, East and West).
- The building's plan layout mainly influences solar gains (orientation and shading coefficients), heat transfer to the ground (exposed perimeter) and the compactness factor of the building. Overhangs and obstructions from the horizon are not addressed in the tool.
- Given the importance of the airflow rate and the techniques to reduce the energy need, the tool allows to set different airflow rates for the heating and cooling modes.
- It is also possible to assess the effect of a mechanical heat recovery system by defining its technical characteristics and the fraction of the airflow that goes through the heat recovery unit.

The properties of all opaque and glazed elements are extremely important in the thermal performance of the building. Moreover, the characteristics of the insulation layers should be adequate with respect to the climate conditions, as well as the glazed elements. The U-value should also be adequate for the type of element of the envelope. Given the importance of a thorough study of these aspects, the tool is prepared to deal with their key parameters, namely: i) U-values; ii) absorption coefficient for solar radiation; iii) internal heat capacity; iv) solar heat gain coefficient (SHGC). In addition, as the opaque elements of the envelope are selected within the macro-components scheme, the software possesses an algorithm to deal with the variation of the thickness of the layers. This allows for the calculation of the U-value in bridged elements (e.g. thermal bridges formed by cold formed steel profiles) according with the method presented in ISO 6946 (2007) and improved by Gorgolewski (2007). The internal heat capacity is also calculated in the tool under the guidance of the simplified calculations given in ISO 13786 (2007).

Another feature of the tool is the possibility to choose the type of ground floor to compute the heat losses to the ground. Figure 13 illustrates the three types of solutions implemented, namely: i) slab on ground floor; ii) suspended ground floor; and iii) heated basement.



a) Slab on ground floor | b) Suspended ground floor (crawl space) | c) Heated basement

Figure 13. Types of ground floor solutions available in the tool.

To assess the effect that shading devices may introduce to the behaviour of the building, several types of movable shading devices are available in the tool and also the option to assign user defined values. The effect of automated shading devices is accounted for through the calculation of the fraction of the day in which the solar incident radiation on a given orientation exceeds a predefined set-point. In ISO 13790 (2008) this parameter is defined as $f_{sh,with}$. Furthermore, the effect of night window protection device activation is taken into account by a correction of the U-value of the window with a factor, f_{shut}, which is dependent of the accumulated difference of hours with and without shading device (Annex G of ISO 13790). In the web-based tool, the night heating effect is disregarded.

The consequence of different solutions for the building services in the analysis are computed, especially, in the delivered energy and the reduction factor for intermittent cooling or heating. To allow the study of these parameters, it is possible to choose the systems' efficiency (typical values of these systems are also provided) and their working schedule. As conversion factors for primary energy vary with the country where the building is located and the reference year, the user may also provide its country values, in order to convert delivered energy into primary energy.

Energy consumption in buildings is influenced by the type of utilization, occupancy and schedule (Guerra Santin *et al*. 2009) and by the user's behaviour (Reinhart 2004). The tool is able to take different operation schedules into account through the calculation of a reduction factor, according to ISO 13790 (2008), which enables calculation with intermittent heating and cooling (see Equations (9) and (10)). The user may then provide information regarding the schedules for space heating and cooling systems. The internal heat gains regarding the occupancy and lighting schedules and heat flows are also taken into account by default (Table 15) or with user defined values.

Table 15. Internal heat gains according to type of building (ISO 13790, 2008).

Human Factors	**Default values**	
Utilization Type:	Internal Heat Gains	Occupancy Schedule
Residential	1 to 8 W/m^2	12 h/day
Offices	1 to 20 W/m^2	6 h/day
Commercial or Industrial	10 W/m^2	6 h/day

In order to improve the estimation of the energy efficiency of buildings in early stages of design using the monthly quasi-steady-state approach, the approach was calibrated using the test-cases of EN 15265 (2007), for five climatic regions according to the Köppen-Geiger map: Csa, Csb, Cfb, Dfb and Dfc.

The calibration factors were quantified for two distinguished cases in terms of the use of a shading device: with and without shading devices. Table 16 and 17 provide the correction factors, for the option with shading devices and without, respectively. Moreover, since the tool allows for considering different shading devices activation modes in the winter and summer, the calibration factors of Table 16 were implemented in the cooling mode and the ones of Table 17 in the heating mode.

Table 16. Obtained calibration factors when solar shading devices are activated.

	Shading devices ON											
	Heating mode						Cooling mode					
Region	a_{H0}	τ_{H0}	Qtr	Qve	Qsol	Qint	a_{C0}	τ_{C0}	Qtr	Qve	Qsol	Qint
Csa	1.00	15.67	1.00	1.00	0.90	0.93	1.20	15.00	1.07	1.00	0.83	0.90
Csb	1.33	15.00	1.00	1.07	0.97	0.93	1.10	15.00	1.03	1.10	0.97	1.00
Cfb	1.33	15.00	0.93	0.83	1.10	1.07	1.30	15.00	1.00	1.00	1.00	1.03
Dfb	1.30	14.67	0.83	0.90	1.25	1.25	1.00	15.00	1.07	1.07	0.97	1.00
Dfc	1.25	14.33	0.83	0.83	1.17	1.50	1.00	15.00	1.00	1.00	1.00	1.00

Table 17. Obtained calibration factors when solar shading devices are not activated.

	Shading devices OFF											
Region	a_{H0}	τ_{H0}	Qtr	Qve	Qsol	Qint	a_{C0}	τ_{C0}	Qtr	Qve	Qsol	Qint
Csa	0.93	15.00	1.00	1.00	1.03	1.03	1.25	15.00	1.17	1.33	0.83	0.90
Csb	1.13	15.00	1.00	0.97	1.03	1.00	0.93	15.00	1.08	1.17	0.87	0.87
Cfb	1.17	15.00	1.00	0.93	1.00	1.03	1.08	15.00	1.08	1.33	0.90	0.87
Dfb	1.33	15.00	0.93	0.87	1.17	1.10	1.20	15.00	1.00	1.00	0.83	0.90
Dfc	1.50	14.00	0.80	0.80	1.07	1.20	1.00	15.00	1.17	1.17	0.92	0.90

Alternatives ranking

After quantifying the performances required the software should interact with the user by notifying her/him that the calculation is finished and that the results were saved. Also, users should be asked if they are willing to assess other building alternative and compare it with the previous one. If yes, the software must return automatically to the input part, and allow the user to fulfil it again with the new alternative. This process should run in loop until the user states that she/he does not have any other alternative to access. Only after that, the software should be able to compare them through the MCDA.

To obtain the optimised solution, the MCDM model should be able to rank the different alternatives taking into account the criteria proposed. In this sense, a matrix should be constructed, presenting the performance of each solution to each indicator. The importance of each criterion (weighting factors) shall be decided by a panel of stakeholders and experts by survey. The preference values for the decision-making are to be defined according to the hierarchy structure presented in Figure 14.

PREFERENCES OF STAKEHOLDERS ⇨ WEIGHTING OF INDICATORS ⇨ SURVEY (??)

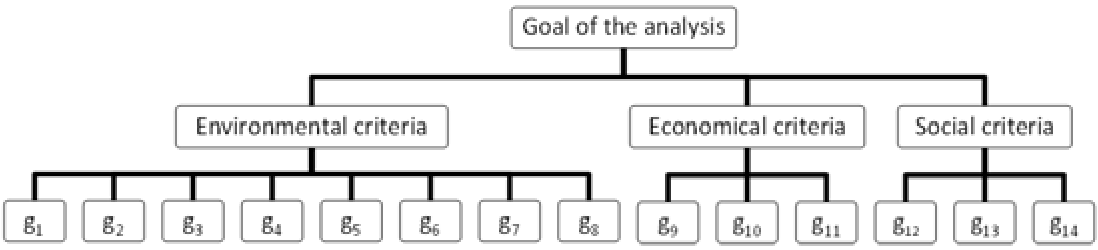


Figure 14. Hierarchal representation of the data and weighting factors.

Notwithstanding, considering the aim of sustainability, for the pilot version of the platform, the same importance can be given to all criteria. Thus environment, social and economic dimension should account for 1/3 each for the whole building sustainability performance.

According to PROMETHEE II (the MCDM model chosen), the ranking of alternatives is given by the balance between the positive and negative outranking-flows.

After this, a sensitive analysis shall be performed considering the use of benchmark solutions, to assess the robustness of the analysis. The proposed approach fulfills the aims of the analysis and managed the uncertainty associated with the evaluation of criteria in a very successful way. The results of the analysis will provide useful information to the decision maker in relation to best and worst options in relation to building design through its life cycle.

2.3 Concept of sustainable steel-intensive renovation (WP 3)

The Work Package 3 studied applicability of the assessment method proposed for the early design stages of new building projects to renovation projects, focusing on deep structural renovations and functional upgrading. The WP was divided to four Tasks. It produced two technical deliverables and the milestone report 'Pre-design issues and indicators for the decision-making methods and platform'.

2.3.1. Characterisation of steel-intensive renovation solutions in the framework of typical renovation objectives (T 3.1)

As a starting point, the word renovation was defined as activities aiming to improve technical, functional or economic value of the building, which are not ordinary maintenance or cleaning. Terms such as improvement, adaptation, upgrading, rehabilitation, modernization, conversion, retrofit, and repair are related to renovation. Activities may concern structural, technical or space systems of the building.

The potential of constructional steelwork in the renovation sector, markets and needs were studied in Spain and Finland. Offering of manufactures to identified application areas was studied based on web-site visits, discussions in the ECCS TC14 and interviews. Competitiveness of steel-based solutions was qualitatively assessed. Two renovation cases were studied in regards to the design and construction process and typical steel-based solutions. Potential of novel and emerging technologies for renovation solutions was also studied.

Use of steel in renovation projects was categorized as structural and functional. In the latter category, energy efficiency improvement has become a major type of activities. In strengthening projects, amount of on-site and manual work can be substantial. In functional use, other properties of steel than strength of material are of importance, too. Sustainability also means the ability to accommodate to changed requirements and take up the challenge of time. The benefits of steel-intensive solutions in building renovations are presented in Table 18.

Table 18. Benefits and competitive edge of steel-intensive solutions in various renovation projects.

Scale and type	Degree of change	Objectives Type of renovation	Benefits and competitive edge of steel
Small / Type I	Low	Upgrading of surfaces, minor extension; strengthening of existing structures; loft conversion; change of roof shape; Type I allows use of the existing building	For strengthening, practically no substitutes on markets; steel products and components available for minor and small scale renovations; roofing solutions and services highly competitive
Medium / Type II	Substantial	Strengthening of a building externally; major upgrading of surfaces, structures or services, structural alterations; modular extension on a roof; several simultaneous objectives Type II may change the use of a building	For strengthening, practically no substitutes on markets; many types of steel-based solutions available for major envelope renovations
Large / Type III	Drastic	Reconstruction of new building behind existing façade; extensive alterations for conversion to new use or occupancy Type III demolishes major parts of the existing building and may change totally the function of a building. Occupants need to move out.	Steel and composite structures allow efficient processes and logistics

Competitiveness of steel-based products and components on European renovation markets was qualitatively studied based on the studies in WP1 and WP2 considering typical use of steel in renovation projects. It was concluded that the strengths of steel are similar with new buildings: Steel has strong advantages on the market thanks to off-site manufacture and advanced logistics.

The envelope renovations were observed to have a big potential but a challenge for manufacturers of steel-based solutions, and the competition is hard. Several types of components and technologies are already available to improve appearance and energy-efficiency, but so far solutions tend to be project-based. It was concluded that there is a need of mass-market solutions that could be customised, and most importantly to be prefabricated and installed fast with small disturbances to occupants.

Table 19 summarizes typical steel-based components in the various types and concepts of renovation projects.

Table 19. Typical steel-based components for renovation projects.

Concept	Structural safety	Energy-efficiency	Usability upgrading
Type I	Individually designed structures for strengthening Combination of structures on markets	Pipelines Shading Solar panels	Acoustic and decorative sheets Ramps, rails Small roofings
Type II	Steel and composite structures for frames and floors Piles, foundations	Façade panels Cassettes Roofings Purlins Eco-piles	Balconies Elevator shafts Modules for extensions
Type III	Steel and composite structures for frames and floors Piles, foundations	Roofings Façade panels Cassettes Purlins Eco-piles	Components of structural renovation Balconies Elevator shafts Modules for extensions

The renovation projects influence on the life-cycle stage of an existing building differently. Type I of small-scale renovation actions extends usually the service-life and thus the use stage of a building, and it can be done with small amount of demolishing activities. The amounts of demolishing and new building activities are greater in type II renovations, and type III may mean that a new building is built which results to the second life cycle. Type II is a combination of old and new, and various parts of a building are possibly in different stages of a life-cycle.

2.3.2 Analysis of renovation solutions in respect to sustainability goals (T3.2)

Special features of renovation projects were studied in respect to the various sustainability indicators. Motivation of a renovation project may often be related to social indicators like for example to accessibility. For this reason, it is important to learn to the differences of decision-making issues between a new building project and a renovation project. Manufacturers of steel-based construction products have a great deal to offer to sustainable building. There is a clear strategy to steel market as a sustainable material and develop technologies that help to save environment and climate as well as to support economic and social welfare.

A renovation project can take place at various ages of a building during the use stage. A great variety of scales of a renovation project exists as described in the project deliverable D3.1. Thus a renovation project may present all the stages of a life-cycle simultaneously with the use phase of the existing building:

- Type I – renovation means small-scale refurbishments without changes in functions or systems of a building; upgrading of surfaces, minor extension; strengthening of existing structures;
- Type II – influences on the operation and use of the building through medium-size changes in the existing building; major upgrading of surfaces, structures or services, structural alterations; vertical extensions; new elevators inside or outside the building; several simultaneous objectives;
- Type III – includes remarkable amounts of demolishing works of non-functional parts or degraded parts of the building; Reconstruction of new building behind existing façade; extensive alterations for conversion to new use or occupancy. Requires move of residents and users to move out during construction work.

Renovation types II and III means in practice a second life-cycle of a building. In fact, instead of a unique cycle, due to the combination of existing elements and new added ones, various cycles can appear overlapped with different stages of development coexisting (Figure 15).

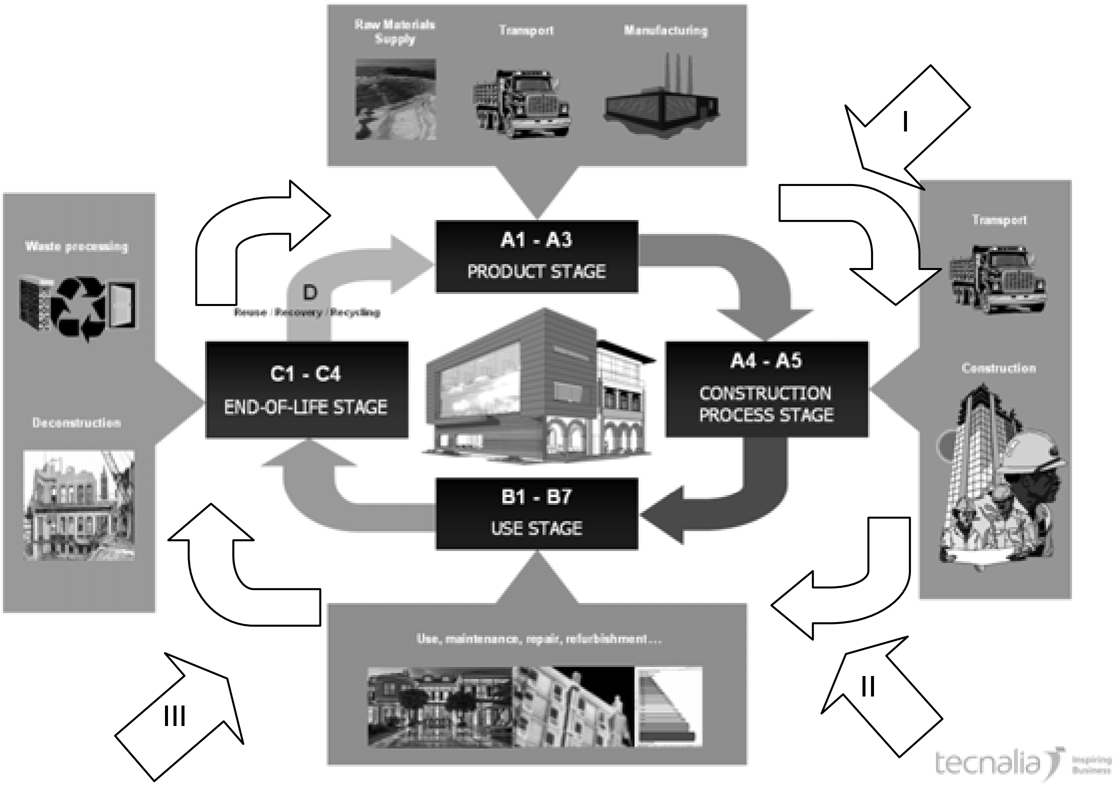


Figure 15. Life-cycle of an existing building during a renovation project: In type I project, small-scale works are made to the building; in type II renovation, parts of the existing building is in use when medium-scale changes are made around and inside the building (phases A1–B7, type II renovation); in type III renovation, parts of the building are demolished and replaced by new solutions.

Steel-based solutions are regarded as highly competitive in the renovation types I and II when renovation concerns strengthening of existing structures or structural renovation. In some occasions, fibre reinforced plastics are used to same purposes as steel but steel's position is strong.

In type III renovations, competitiveness depends on the level of prefabrication and services offered to building owners. Tightening European regulation has directed high interest in renovation projects in which envelope structures are upgraded; steel based solutions comprise new roofing and facades with thermal insulation. These solutions also allow architectural changes in the appearance of a building; additional components such as elevator shafts and balconies can be included to improve accessibility and well-being. Extensions on roofs or around the existing building are often benefiting from steel construction technologies thanks to, for example, lightness, strength, precise tolerances, easy assembly and logistics. However, the substituting solutions are available and competition resembles that in the new building segment. Opportunities of steel-based products in respect to sustainability goals in renovation projects are presented in Table 20.

Table 20. Renovation solutions in respect to sustainability goals.

<table>
<tr><th colspan="2">Integrated renovation solutions focused to improve energy-efficiency</th></tr>
<tr><td colspan="2">Integrated solutions including thermal inertia will minimize HVAC energy consumption and also improve user comfort. At the same time, emissions, produced as consequence of combustion process, will also be minimized.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>- Lightweight steel solutions.
- Integrated solutions.
- Well-finished products.
- Flexible solutions.</td><td>- Raw material supply and transport: A1, A2.
- Use and operational energy: B1, B6.
- Social: Health and comfort.
- Economic: Use costs.</td></tr>
<tr><th colspan="2">Solar Shading Systems</th></tr>
<tr><td colspan="2">Solar shading systems controls heat and glare while delivering significant reductions in solar heat gain.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>- Lightweight steel solutions.
- Well-finished products.
- Solar shading integrated systems.
- Flexible solutions.</td><td>- Raw material supply and transport: A1, A2.
- Use and operational energy: B1, B6.
- Social: Health and comfort.
- Economic: Use costs.</td></tr>
<tr><th colspan="2">Renovation solutions that optimize the orientation</th></tr>
<tr><td colspan="2">An adequate planning of building orientation can reduce energy consumption. The indoor air quality can also be improved.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>- Flexible solutions.
- Integration of automatic systems.
- Adaptability.
- Lightweight steel solutions.</td><td>- Raw material supply and transport: A1, A2.
- Use and operational energy: B1, B6.
- Social: Health and comfort.
- Economic: Use costs.</td></tr>
<tr><th colspan="2">Façade insulation systems</th></tr>
<tr><td colspan="2">These solutions will minimize not only HAVC energy consumption but also user comfort. At the same time, emissions, produced as consequence of combustion process, will also be minimized.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>FAÇADE INSULATION
- External insulation
- Internal insulation
- Intermediate layer insulation
ROOF INSULATION
- External insulation
- Internal insulation
- Lightweight steel solutions.
- Integrated solutions.
- Well-finished products.
- Flexible solutions.
Etc.</td><td>- Raw material supply and transport: A1, A2.
- Manufacturing: A3.
- Construction/Installation: A4.
- Use and operational energy: B1, B6.
- Social: Health and comfort.
- Economic: Use costs.</td></tr>
<tr><th colspan="2">Passive cooling systems</th></tr>
<tr><td colspan="2">The installation of an evaporative cooling system consumes less energy during the use phase compared to other air conditioning systems. This results in lower fuel consumption and therefore raw materials. At the same time they minimize emissions, from combustion, of greenhouse gases and other compounds that can affect human health or ecosystems. These systems also have positive effect on the comfort of home users.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>- Lightweight steel solutions.
- Integrated solutions.
- Flexible solutions.</td><td>- Raw material supply and transport: A1, A2.
- Use and operational energy: B1, B6.
- Social: Health and comfort.
- Economic: Use costs.</td></tr>
<tr><th colspan="2">Integrated energy renewable resources instead of conventional energy resources</th></tr>
<tr><td colspan="2">The use of renewable resources reduces fuel consumption that will avoid raw material consumption. At the same time, emissions, produced as consequence of combustion process, will also be minimized.</td></tr>
<tr><td>Opportunities for steel</td><td>Main sustainability goals</td></tr>
<tr><td>- Lightweight steel solutions.
- Self-sufficient solutions.</td><td>- Raw material supply and transport: A1, A2.
- Use and operational energy: B1, B6.</td></tr>
</table>

- Integrated solutions. - Green market.	- Social: Health and comfort. - Economic: Use costs.
Use information about the environmental characteristics of products	
The use of EDPs (Environmental Product Declarations) provides a better environmental performance for each product.	
Opportunities for steel	**Main sustainability goals**
- Steel products with EDP. - Optimization of products and processes.	- Raw material supply and transport: A1, A2. - Use and operational energy: B1, B6. - Social: Health and comfort. - Economic: Use costs.
Industrialised construction	
As for the industrialization of construction, we understand it as an organization of the production process that involves the application of advanced technologies in the comprehensive process of design, production and management, from the perspective of a logic that defines industrialization as a combination of: RATIONALIZATION + PREFABRICATION + AUTOMATION	
Opportunities for steel	**Main sustainability goals**
- Integrated and prefabricated solutions. - Automation of steel solutions production. - Optimization of products and processes. - Rationalisation of steel. - Lightweight steel solutions. - Self-sufficient solutions. - Flexible and dismountable solutions. - Adaptability. - Recyclability.	- Raw material supply and transport: A1, A2. - Use and operational energy: B1, B6. - Social: Health and comfort. - Economic: Use costs.
Use of recycled materials	
The use of recycled materials minimizes impact from raw material supply, transport, end-of-life, etc.	
Opportunities for steel	**Main sustainability goals**
- Rationalisation of steel. - Optimization of products and processes. - Green market.	- Raw material supply and transport: A1, A2. - Use and operational energy: B1, B6. - Social: Health and comfort. - Economic: Use costs.
Open systems	
Open systems produce less waste during use changes, resulting in a decrease in consumption of raw materials and land cover for landfill use. Additionally they promote flexibility, reuse and minimisation of raw materials, leading to a reduction in resource consumption and, therefore, to the conservation of the environment.	
Opportunities for steel	**Main sustainability goals**
- Lightweight steel solutions. - Flexible and dismountable solutions. - Adaptability. - Well-finished products. - Recyclability.	- Raw material supply and transport: A1, A2. - Use and operational energy: B1, B6. - Social: Health and comfort. - Economic: Operational costs.
Use of fast and dismountable mechanical connections	
Such joints reduce the waste generated in the replacement of individual parts during maintenance. It is also improved the possibility of separating waste, which increases their recyclability. A building designed and built using principles of flexibility, allows a decreased waste generation in the future uses and additionally promotes reuse and recycling of materials.	
Opportunities for steel	**Main sustainability goals**
- Lightweight steel solutions. - Well-finished products. - Flexible and dismountable solutions. - Recyclability.	- Raw material supply and transport: A1, A2. - Use and operational energy: B1, B6. - Social: Health and comfort. - Economic: Operational costs.

The different modules of life-cycle can be quantified independently thanks to the concept of modularity presented in CEN standards. On this way, the refurbishment project from the original building can be assessed as a new whole life-cycle. This concept can be applied even to single products.

In the Work Packages 1 and 2, the basics of selection of indicators were studied. The European standardization work in the Technical Committee 350 of CEN was adopted as the framework to develop the methodology for the early stages of a new building project. Renovation solutions can be assessed in respect to two extreme options that are a complete demolishing or no renovation in addition to the various scales of intended changes in technical or functional performance of the building. The number of alternative solutions may become so big that selection of key indicators is reasonable. Typically, assessment results are used to comparisons of either direct values of indicators of alternatives or weighted scores aggregated in a process.

Environmental indicators are based on the information about volume (weight) of materials consumed during the production and construction stages A1–A4. The older a building is the less such data can be found from drawings or other documents. For this reason, selection of a limited number of key indicators is often a choice to which targets or criteria can be presented. For example, a reasonable key indicator is energy consumption of the renovated building compared to the existing one. The impacts of various technologies can be assessed solution by solution or at the level of an entire building.

The various targets of a renovation project are given first of all by the owners of the building. There is a great variety of the types of owners which influences on the project planning. In residential buildings, there can be tens of shareholders; office buildings often have only one owner although there can be several companies as tenants. Some owners may have a building stock by themselves like in social housing often is the case. However, in each case the starting point of a renovation project is setting the targets or criteria. This can be done together with an architect or an entire design team as well. Regulation gives some target values and requirements for the level that needs to be achieved.

By analysing different methodologies, it was verified that it was important to address all the indicators addressed for new buildings. The only difference identified was to evaluate the improvement obtained by renovating the building, regarding energy consumption and comfort indicators. In this sense, the indicators to be included in the SB_Steel methodology for renovation projects are the same as for new building projects, as well as their assessment process.

2.3.3 Macro-component approach to a renovation case-study (T3.3)

The suitability of macro-component approach to renovation projects was considered for the two main types solutions. In principle, the envelope macro-components and their data can be prepared like for new buildings. The same holds structural strengthening but the benefits of the approach for decision-making in early design phases are smaller as the uniqueness of solutions is obvious.

Structural strengthening and upgrading

A great variety of steel products such as beams columns and sheets are usable in structural strengthening and upgrading projects of existing buildings. The amount of steel consumed varies also greatly; in some projects existing beams are strengthened with additional steel parts fixed at the bottom or sides, in some projects new intermediate floors or a new external building frame has been built. The superiority of steel in this market is based on the qualities of products and accurate deliveries. Typically, design of solutions is made case-by-case. Thus, sustainability indicators can also be selected case-by-case. In the case of components such as floors, data from the SB_Steel databank or data of manufacturers might be usable.
For the purpose of SB_Steel macro-components database and for the time being different hot rolled I-section and tubular profiles will be addressed. The components to be addressed are the ones presented in the ECCS Steel LCA calculator, iphone app, developed by CMM (Portuguese Steelwork Association).

Energy renovation

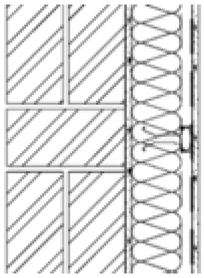
Reduction energy consumption and elimination wastage it is a main goal of the EU, Directive 2010/31/EU. This Regulation applies to a new, existing buildings and building elements. It supports opportunities to improve indoor comfort level, reduce energy consumption in buildings and thus reduce their CO_2 emissions by making smart energy saving choices to achieve carbon neutrality of buildings.

It is possible that selection of solutions for energy renovation is made solely based on energy consumption as the indicator. Additionally, renewable and non-renewable sources of energy can be valued. Other indicators can be selected according to simultaneous objectives such as indicators for comfort (indoor air, noise, appearance). Recently, European projects have made proposals for simplified approaches for sustainability assessment of envelope renovations.

There are three possibilities to add extra thermal insulation into an external wall:

- A new inner surface layer and additional insulation on the old inner surface of a wall (Figure 16);
- The old thermal insulation replaced with more efficient material;
- A new outer surface layer and additional insulation on the old outer surface of a wall.

These solutions can be combined and applied together to improve the thermal insulation efficiency.



Components

Ref.no.	Material	Thickness (mm)
1	Gypsum board	12.5
2	Airtightness membrane	0.2 – 0.43
	Mineral wool	100
-	Steel	kN/m2

Thermal transmittances

U (W/m2. °C)	$U_{bridging}$ (W/m2. °C)
Final - 0.16-0.3	

Figure 16. Example of external wall renovation solution for the inner surface.

During case studies on renovation projects in WP3 and WP5, it was noted that steel facilitates lightweight industrialized solutions for renovation projects which allow for less waste on site. Steel solutions can also be developed with a high flexibility to cover multiple objectives.

2.3.4 Model for decision-making platform in early stages of a building refurbishment project (T3.4)

The model for incorporation of renovation macro-components to the decision-making platform was prepared based on the case studies and preceding tasks.

The macro-components for a renovation project were developed and presented alike to what was developed for new buildings macro-components database, and the renovation macro-components database was presented the life cycle assessment of each macro-component. The procedure adopted to perform the macro-components analysis was the same as developed for new buildings.

The structure developed for new buildings was observed as usable for renovation cases. The structure is divided in three stages: (i) input, (ii) engine and, (iii) output. The input phase collects general data regarding the building and the type of renovation, gave by the user. The engine part, quantifies the impacts (environmental, economic and social) for each solution. In this case, renovation projects, also the original building shall be addressed in order to identify the improvement potential of each of the solutions considered. The calculations and the decision-making methods used for renovation projects are the same as the ones presented for new buildings. At last, the output phase gives the results obtained.

2.4 Development of software tool (WP 4)

Work package 4 produced the decision-making aid for sustainable design of steel-framed and steel-intensive building projects. The software can also be used for renovation design when the building components are presented as macro-components. The outcome was also reported in two technical deliverables.

2.4.1 Conceptual development of the architecture of the software: assembly of general methodology for environmental and energy assessment of steel framed buildings (T4.1)

This task developed the general framework for software that handles the environmental assessment and the energy performance of a building in the early stages of design. Therefore, the aim of the software was set as the evaluation of different building solutions in two distinct stages of a building project: (i) the conceptual stage, and (ii) the pre-design stage. In the conceptual stage in particular, the availability of data is scarce. Thus, two different algorithms were developed in order to address both stages of design. The complete flowchart of the program is illustrated in Figure 17.

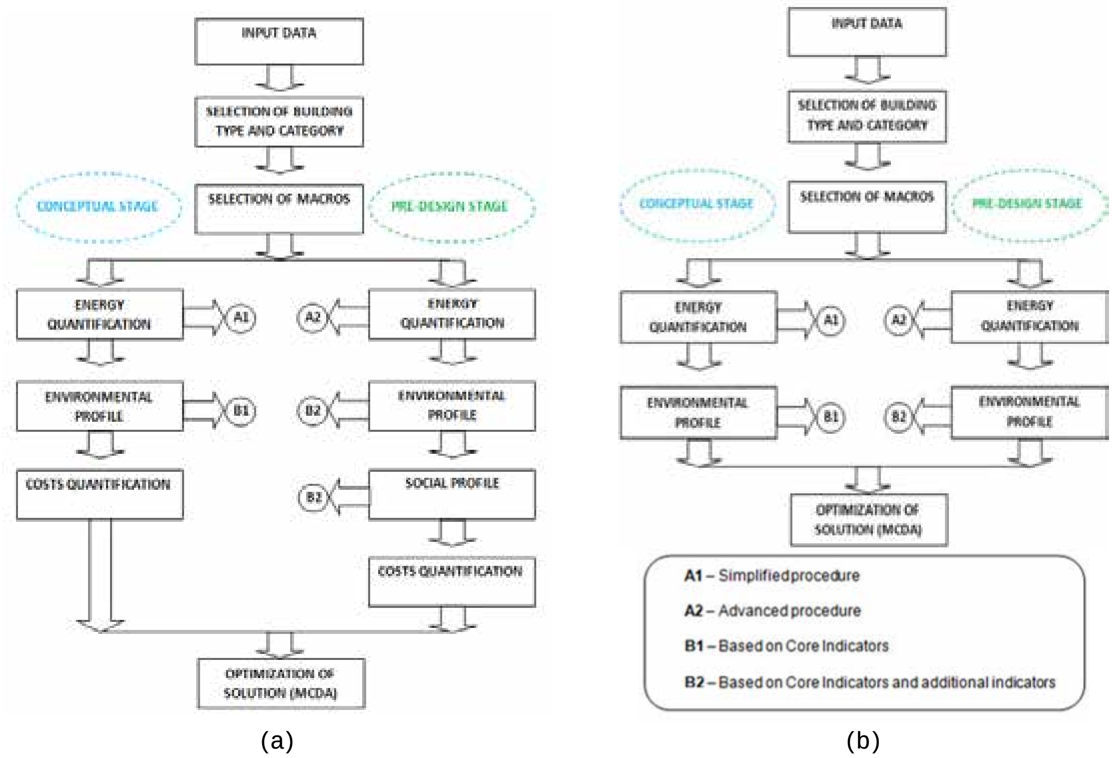


Figure 17. Framework for the SB_Steel methodology: a) Initially planned framework; b) implemented framework.

The first stages of the algorithm and the final stage are common to both routes: the input of data, the selection of the building type and category (according to the classification matrix defined in WP1) and the selection of the macro-components from the database (from the database created in WP2). Then, from this stage two different algorithms were implemented in order to address the availability of data in the conceptual stage and in the pre-design stage. In the conceptual stage the quantification of environmental criteria and energy requirements is based on simplified procedures, while in the pre-design stage, more complex procedures will be adopted.

The subsequent step, the optimization procedure, is again common to both routes. In this model, a multi-criteria decision approach was implemented in order to address the different criteria involved in the analysis.

2.4.2 Flowcharting and organization of the environmental component of the methodology (T4.2)

This task was for implementation of the macro-component approach developed in WP2 and WP5 and the modular concept of the recent CEN assessment standards to software.

The quantification of environmental impacts of a building was based on different scenarios at three levels, i.e., materials/products, macro-components and building, according to EN 15978:2011 and EN 15804:2011. Both standards propose the quantification (and presentation) of potential environmental impacts and energy need through a modular system consistent with the several stages of the life cycle of materials/products and building. This aims for a better sensitivity in terms of understanding the environmental burden of a given stage, allowing for the optimization of the environmental performance of the building. The modular system implemented in the software is synthesized in Figure 18. The description of the modules is the following:

- A1:A3 – Product stage;
- A4:A5 – Construction process stage;
- B1:B7 – Use stage;
- C1:C4 – End of life stage;
- D – Benefits and loads beyond the system boundary.

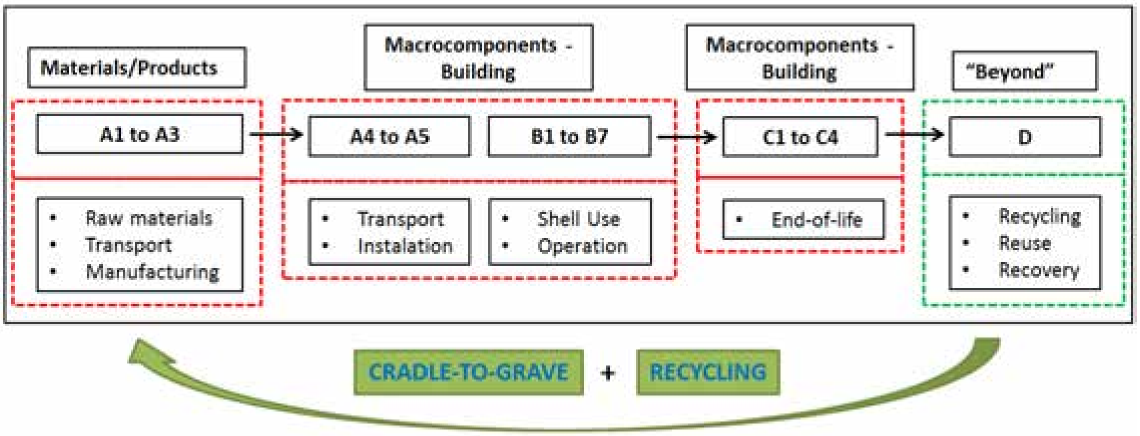


Figure 18. Modular information of materials/products, macro-components and building.

Loads and benefits resulting from reuse, recycling and energy recovery are assigned in Module D, which is an optional module. In a cradle-to-grave analysis the general system boundary of the macro-component is illustrated in Figure 19.

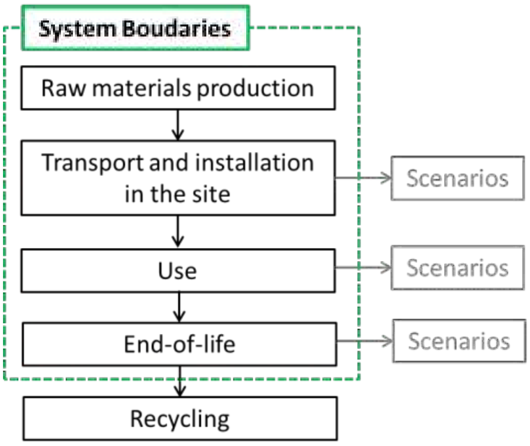


Figure 19. Macro-components system boundaries.

Some stages were quantified based on scenarios. In order to describe scenarios in a transparent and objective way, a series of tables were formulated to allow a complete description of the scenarios considered for a given stage. Figure 20 presents the scenarios considered for the operation stage of a macro-component.

USE STAGE - BUILDING FABRIC MODULES B1:B5			
			Scenario
B1	**Use**	**Process (source,code)**	NA
		Indoor Air	NA
		Soil and Water	NA
		Net potable water (m3)	NA
B2	**Maintenance**	**Maintenance process (source,code)**	NA
		Maintenance cycle (per year)	NA
		Net potable water (l/year)	NA
		Ancillary materials	NA
B3	**Repair**	**Description**	Repainting walls
		Repair cycle (per RSL)	1 (Repaint 50% of the outside surface)
		Wastage material (kg)	NA
		Ancillary materials	NA
		Equipment used	Manual tools
B4	**Replacement**	**Replacement cycle (per RSL)**	1 (Repaint 100% interior surface)
		Wastage material (kg)	NA
		Ancillary materials	NA
		Equipment used	Manual tools
B5	**Refurbishment**	**Refurbishment cycle(perRSL)**	NA
		Material input (kg/cycle)	NA
		Wastage material (kg)	NA
		Further assumptions	NA

Figure 20. Example of the table used to describe scenarios for the operation stage.

As already referred, the development of the macro-components followed the modular concept of CEN standards. Therefore, the output of each macro-component is organized in terms of the modules in each stage, as exemplified in Figure 21.

PRODUCT STAGE
MODULES A1:A3

	A1 + A2 + A3			
Impact Category	**Raw Materal Supply**	**Transport**	**Manufacturing**	**Units**
GWP	4,34E+01			kg CO_2 eq
ODP	1,34E-06			kg CFC 11 eq
AP	1,93E-01			Kg SO_2 eq
EP	2,02E-02			kg $(PO_4)^{-3}$
POPC	2,59E-02			kg Ethene eq
ADP-E	3,76E-01			kg Sb eq
ADP-F	6,59E+02			MJ

CONSTRUCTION PROCESS STAGE
MODULES A4:A5

	A4	A5	
Impact Category	**Transport**	**Construction - Instalation Process**	**Units**
GWP	8,72E-01	0,00E+00	kg CO_2 eq
ODP	1,41E-07	0,00E+00	kg CFC 11 eq
AP	4,79E-03	0,00E+00	Kg SO_2 eq
EP	1,04E-03	0,00E+00	kg $(PO_4)^{-3}$
POPC	1,68E-04	0,00E+00	kg Ethene eq
ADP-E	6,30E-03	0,00E+00	kg Sb eq
ADP-F	1,38E+01	0,00E+00	MJ

Figure 21. Example of the modular information tables.

In addition to the data necessary to quantify the potential environmental impacts of all the elements of the building, there is another component with extreme importance in the environmental performance: the operational energy. Therefore, in the macro-component approach, it is possible to provide the U-value and thickness of the elements, which is extremely valuable to quantify the cooling and heating energy need of the building, as described in the following task.

2.4.3 Flowcharting and organization of the energy component of the methodology (T4.3)

The goal of this task is the development of the algorithm for the quantification of the energy component of the building. The software for the operational energy quantification of the building in the preliminary stage and in the conceptual stage of design is built on three main modules: the input module, the engine, and the output. The algorithm of the software represented in Figure 15 is similar in both stages, although in the preliminary stage of design, the input is simplified due to the lack of data.

The module of input data is sub-divided into three sub-modules: input of climatic data, input of the characteristics of the building's envelope, and input of the systems integrating the building. In the first module, input of climatic data, two major climate parameters must be defined in order to perform energy need calculation: i) air temperature; and ii) solar radiation on a surface with a given orientation.

Then, in the module for the input of the characteristics of the building's envelope the most relevant properties of the building's envelope, together with the orientation of its surfaces, are provided. The energy consumption in a building is influenced by the type of utilization (e.g. residential, office, commercial or industrial), occupancy schedule and by the users' behaviour. Therefore, the type of utilization of a building must be taken into account in energy calculations, as they present a high effect in internal gains through lighting, appliances and metabolism heat flow. Hence, this sub-module enables to describe the patterns of occupancy and users behaviour.

The last input sub-module enables the user to describe the technical systems that are expected to integrate the building. Therefore, in this sub-module the user provides detailed information about the characteristics of the glazed elements, shading devices and overhangs, optical and thermal properties of the opaque envelope, properties of the ground floor and thermal radiation to the sky. The engine is responsible for the quantification of the energy consumption of the building. The methodology implemented in this engine fully complies with the ISO 13790:2008.

The calculation of the energy needed for space heating and cooling is performed taking into account a monthly quasi-steady state method, which relies in correlation factors to simulate the dynamic effects associated with this kind of thermal balance problems. For the space heating, the effect of higher gains (solar and internal) than heat losses, which leads to an overheating effect, is accounted for through the heating utilization factor. In the case of the energy for space cooling, the utilization factor is applied to the heat transfer from the interior of the exterior (losses) in order to include the effect of the losses that are not used to lower cooling loads (periods of low interior temperature). Furthermore, intermittent cooling and intermittent heating situations are addressed in this tool.

Based in the calculation procedures described in the previous paragraph, the building is classified in terms of energy efficiency.

Figure 22 presents the flowchart for the quantification of operational energy in the preliminary stage of design.

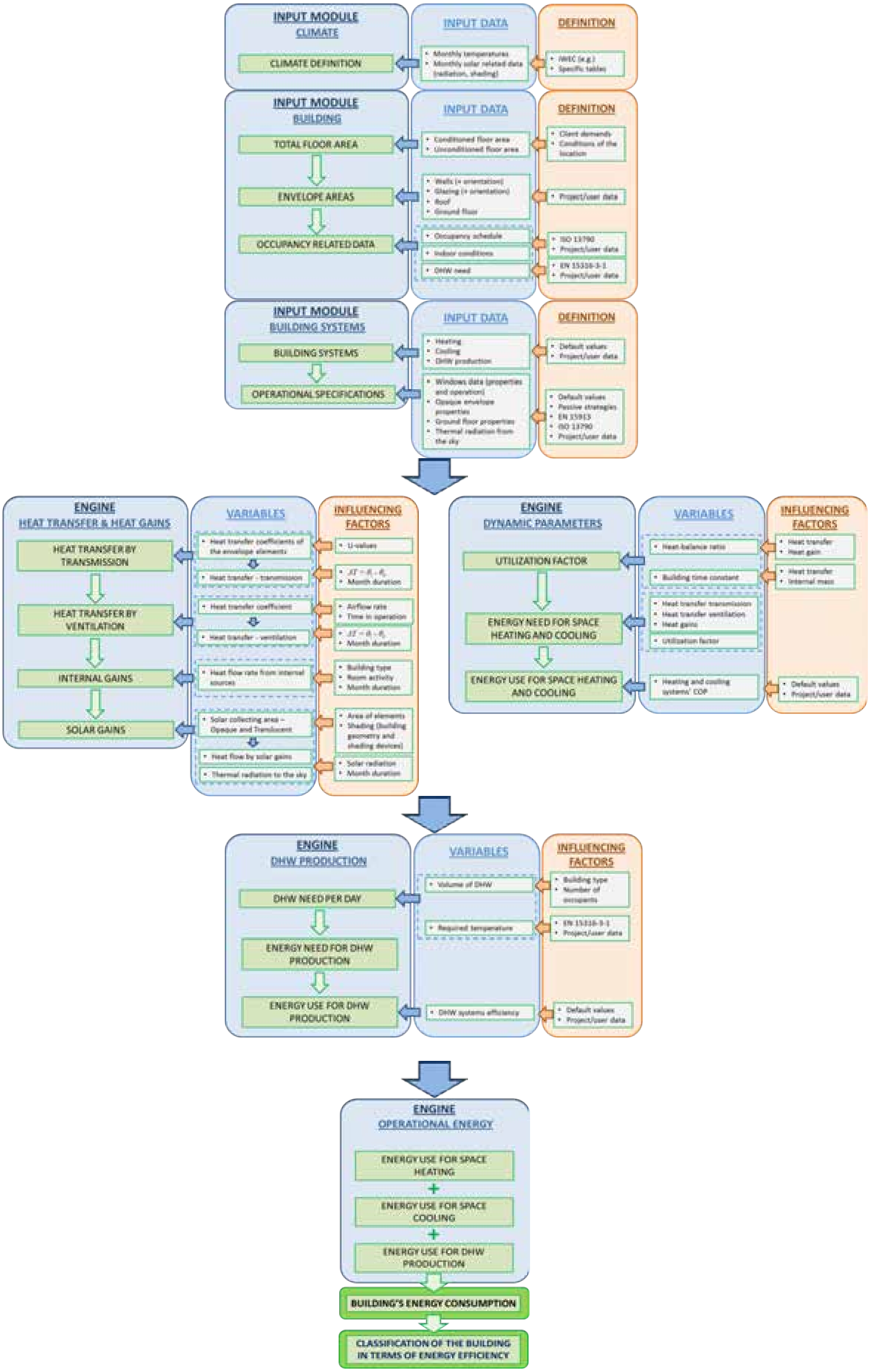


Figure 22. Flowchart for the quantification of operational energy in the preliminary stage of design.

2.4.4 Implementation of the software (T4.4)

The development of the platform for implementation of the software, which is illustrated in Figure 23, was made of two different components:

- a public website enabling the assessment of building sustainability, and
- a private back office for the parameterization of the website.

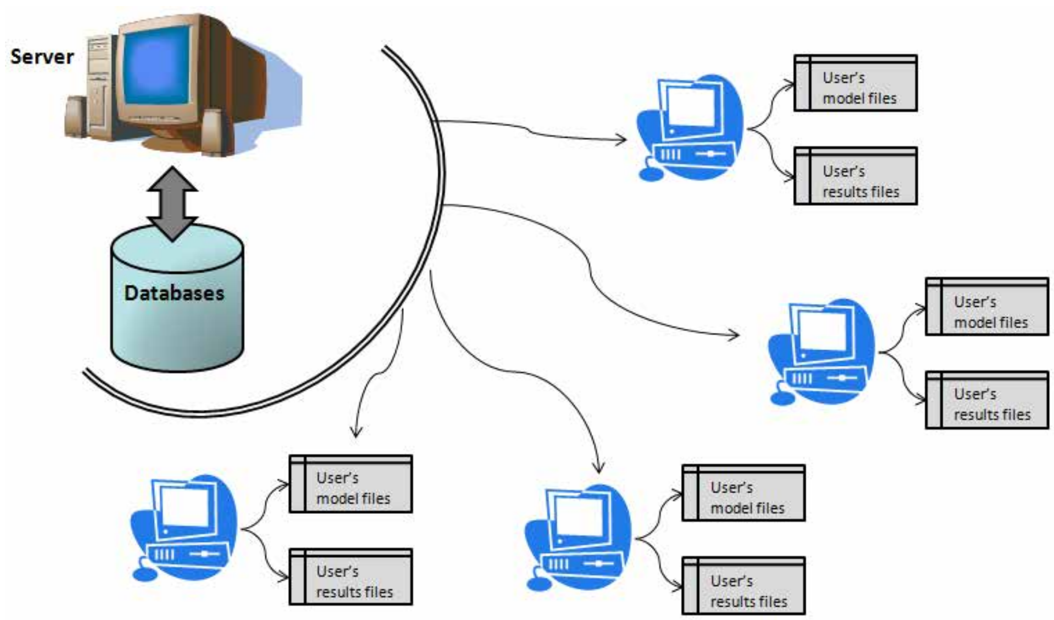


Figure 23. Platform for software implementation: web-based program.

The public website enables the assessment of the sustainability of buildings, which starts with a sequence of screens in which the user specifies the building to assess, selecting the type of building (as illustrated in Figure 24), the appropriate European climate zone, selects the type of analysis (conceptual or preliminary), the characteristics of building and, finally, the selected macro-components of the building.

After the input of all data relating to the building and the type of analysis, the assessment of the building takes place. Then, the user is able to store the results of the calculation and is able to perform alternative designs. Based on the alternative designs, which are stored in the database, and according to the priorities given by the user to each criterion, the program provides a ranking of the alternative solutions. Finally, the user is able to export the results into graphs and reports.

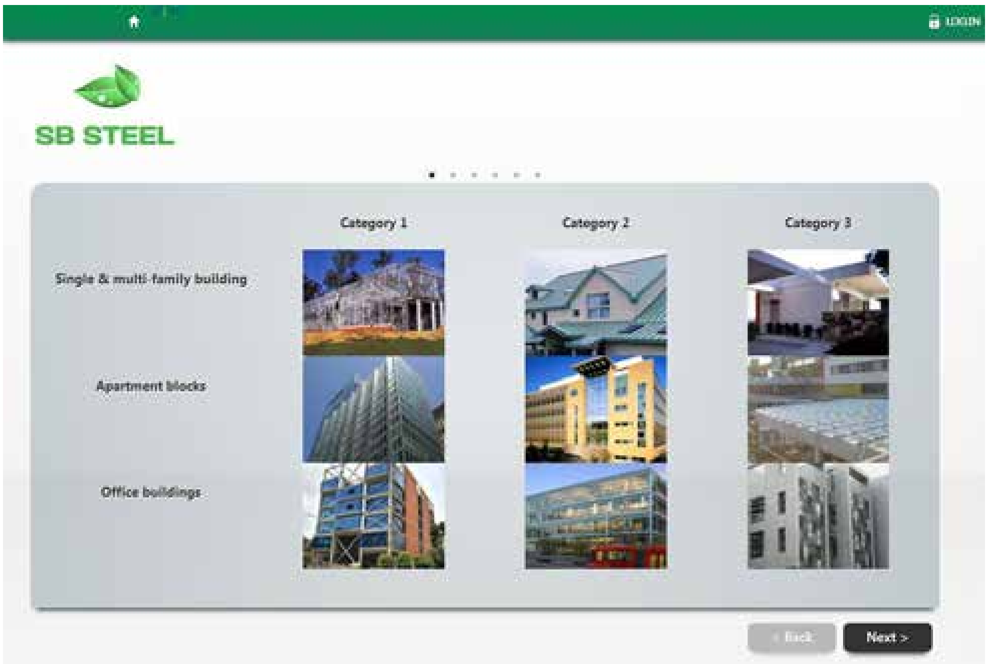


Figure 24. Selection of the building type.

On the other hand, the back office provides support to the management of the contents of the website and to the maintenance of the back office itself (e.g. management of users). The back office enables to manage all content provided in the website (menus, navigation structures, etc.). The editing of some contents, particularly pages with generic information, may be performed by a tool WYSIWYG (CKEditor, TinyMCE or other similar tools) to enable an easy formatting of the content to be presented.

2.4.5 Verification and validation of software (T4.5)

Validation of the software developed in the previous tasks was made through a case study. The case study was assessed by the developed tool over the two stages of design considered in the tool: the concept stage and the preliminary stage. Then, the same case study was performed by other available software, namely, GaBi 6 (2012) and DesignBuilder (2012), for life cycle assessment and energy quantification respectively.

Therefore, the validation of the software was made by a case study: a dwelling located in Coimbra, Portugal. This building is composed of two storeys, with a light-weight steel frame. The results of the several design stages are compared with advanced analyses in order to assess the accuracy of the developed tool.

Assessment in the concept stage of design

General data

The building case was a single family two-storey residential house, with an approximate construction area of 120 m^2. Its location was Coimbra, a town in the middle of Portugal, belonging to the climatic region Csb.

The climatic characteristics of the respective zone were considered in the analysis of the energy consumption of the building for space heating and cooling. The weather data was obtained from the International Weather for Energy Calculations database (IWEC 2001) for Coimbra. The weather data file contains mean hourly values computed for a period of thirty years for several climate parameters. Based on these values, the tool quantifies the monthly values of the air temperature and global solar radiation, as shown in Figure 25.

a) Dry bulb temperature b) Global solar radiation (hor. surface)

Figure 25. Weather data for Coimbra, PT: monthly values (IWEC 2001).

In the concept stage of design, building plans were considered as non-existent. For this reason, the assessment was made on a simplified rectangular area of construction. The total usable floor area was assumed as 240 m^2. The total height of the building was assumed as 6.0 m. Moreover, it was considered that the main façade of the building was facing west. All other data was estimated according to the procedure described in the following sections.

Geometry and envelope

For the rectangular area of the building a width-to-length ratio of 1:2 is considered and the glazing areas in each façade are obtained as a percentage of the respective façade:

- North-oriented: 20%;
- East-oriented: 10%;
- South-oriented: 25%;
- West-oriented: 8%.

Walls and glazing areas in each façade are summarized in Table 21.

Table 21. Building façade areas in the conceptual stage of the case.

Building façades	**North** [m^2]	**East** [m^2]	**South** [m^2]	**West** [m^2]	**Sum** [m^2]
Opaque area	33.5	75.3	31.4	77.0	217.2
Glazed area	8.4	8.4	10.5	6.7	34.0

Macro-components selection

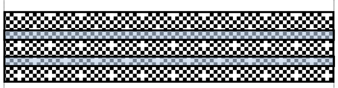
In the early stages of design the designer faces the challenge to select the type of materials and construction system to be used that comply with the required criteria of low environmental impacts and low energy consumption. In this case study, three different construction systems are considered. The first and second construction solutions are assumed to be steel intensive and correspond to a lightweight steel framing solution and a steel structure with hot-rolled profiles, respectively. The third solution is assumed to be a traditional reinforced concrete and brickwork building. Therefore, the first two solutions belong to Category 1, in Table 22, and the last one belongs to Category 3.

Table 22. Matrix for classification of steel buildings.

	Category 1	Category 2	Category 3
Single & multi-family building			
Apartment blocks			
Office buildings			

Hence, from the database of macro-components, different sets were selected (see Deliverable 4.2) taking into account the category of the building and the climatic region. In order to comply with the latter, a maximum value for the thermal transmittance (U) is considered, narrowing the number of appropriate macro-components and enabling an easier selection.
The definition of the properties of the glazed envelope is crucial in the thermal balance of the building. In this case study, the characteristics of the glazed envelope of the building are the same for the three construction solutions. The selected macro-component for exterior windows is presented in Table 23.

Table 23. Macro-component for exterior windows: thermal and optical properties.

	Macro-component reference	Materials	U-value [W/m^{2}K]	SHGC (*)
Exterior windows				
 B2020	B2020 Exterior windows	PVC frame Double glass panes (8 + 6 *mm*, with an air gap of 14 *mm*)	2.60	0.780

(*) SHGC – Solar Heat Gain Coefficient

Data needed for the quantification of the operational energy

In this stage it is assumed that no precise information are available about the use of equipment for space heating and cooling. Therefore, all the parameters necessary for the quantification of the energy needs of the building are estimated as described in the following sub-sections.

Building envelope

The building envelope has a dominant role in the building operational energy consumption. Some of the main relevant parameters related with the building envelope are: (i) the total conditioned floor area; (ii) areas and orientation of external opaque and glazed envelope; and (iii) thermal properties of the materials.

The values of the thermal transmittance for each building component are obtained from the values provided by the macro-components. In case of the construction solution 1, the U-values were obtained taking into account the thermal bridges due to the light-weight steel frame.

Shading devices for the windows are taken into account in order to avoid overheating during the summer season, as well as to provide extra insulation of the glazing components during the night (winter season). If no data is available in this stage (which is usually the case), the thermal and optical properties of the shading devices are taken as the recommended values by ISO 10077-1 (2006), as are indicated in Table 24.

Table 24. Thermal and optical properties of the shading devices.

Element	Solar transmittance	Solar reflectance	R [m^2.K/W]
Shutters	0.04	0.35	0.220*

*shutter and air space included (ISO 10077-1:2006)

Building services

The buildings services include: space heating/cooling (air conditioning), mechanical ventilation, exhaust air heat recover and domestic hot water production. Since, in this stage no data is available, the adopted equipment data is presented in Table 25, based in recommended default values provided by international standards (ISO 13790:2008 and EN 15316-3-1:2007). However, the designer is able to change any of the recommended parameters. The values related with building services are independent of the constructive solution adopted for the building envelope. Therefore, these values are kept constant for the three alternative construction solutions.

Table 25. Building services/equipment default input data.

Building Services	Values
Air conditioning (Set-point 20 °C–25 °C) (1)	COP Heating = 4.0 COP Cooling = 3.0
Energy need for hot water production 2	Efficiency: 0.9
Ventilation and infiltration rate (3) (Constant values)	0.6 ACH (Heating mode) 1.2 ACH (Cooling mode)

(1) from ISO13790 (2008) – Table G.12;
(2) calculated according with EN 15316-3-1 (2007)
(3) depends on air tightness of the building envelope and passive cooling strategies.

Human factor

The human factor plays a key-role in the energy performance of buildings, since buildings are used and controlled by people. The internal heat gains due to the number of occupants inside the building and the use of equipment are of particular importance. Following guidance in ISO 13790 (2008) the occupancy schedule and respective internal gains presented in Table 26 are considered. The use of HVAC equipment is considered only in the period from 17:00 to 23:00, since this is usually the period when occupants are at home and the HVAC system is turned on.

Table 26.Occupancy schedule and internal heat gains (from ISO 13790).

Days	Occupancy period	Living room and kitchen [W/m^2]	Other conditioned areas [W/m^2]
Monday to Friday	07:00 to 17:00	8.0	1.0
	17:00 to 23:00	20.0	1.0
	23:00 to 07:00	2.0	6.0
	Average	9.0	2.67
Saturday and Sunday	07:00 to 17:00	8.0	2.0
	17:00 to 23:00	20.0	4.0
	23:00 to 07:00	2.0	6.0
	Average	9.0	3.83

Likewise, these values are kept constant in the assessment of the three construction solutions.
The results for the three solutions are summarized in Table 27. Solution 1 has a better performance (lower impact) for environmental categories of ADPfossil, EP and GWP. On the other hand, Solution 3 has a better performance for environmental categories of AP, ODP and POCP. Solution 2 has a better performance only for environmental categories of ADPelements.

Table 27. Life cycle environmental analysis results, in the concept stage.

Concept stage	Solution 1	Solution 2	Solution 3
ADP elements [kg Sb-Equiv.]	1,68E-01	8,00E-02	2,44E-01
ADP fossil [MJ]	5,37E+05	8,89E+05	7,48E+05
AP [kg SO2-Equiv.]	1,63E+02	1,86E+02	1,56E+02
EP [kg Phosphate-Equiv.]	1,87E+01	2,49E+01	2,41E+01
GWP [kg CO2-Equiv.]	4,36E+04	9,05E+04	8,96E+04
ODP [kg R11-Equiv.]	1,24E-03	1,46E-03	6,53E-04
POCP [kg Ethene-Equiv.]	4,26E+01	5,13E+01	2,87E+01

In the concept stage, the energy needs for space heating and cooling, for the three solutions, are indicated in Table 28.

Table 28. Energy need for space heating and cooling assessed in the concept design stage.

	Solution 1		**Solution 2**		**Solution 3**	
	$Q_{H,nd}$	**$Q_{C,nd}$**	**$Q_{H,nd}$**	**$Q_{C,nd}$**	**$Q_{H,nd}$**	**$Q_{C,nd}$**
JAN	217.6	0	256.2	0	238.5	0
FEB	155.1	0	108.1	0	110	0
MAR	99	0	34.4	0	40.3	0
APR	72	0	0	0	0	0
MAY	0	8.5	0	0	0	0
JUN	0	419.7	0	175.5	0	185.3
JUL	0	546.7	0	411.4	0	418.5
AUG	0	483.1	0	357.4	0	364
SEP	0	411.5	0	226	0	234.2
OCT	0	3.1	0	0	0	0
NOV	129.8	0	79	0	81	0
DEC	188.6	0	205.8	0	190.7	0
TOTAL (kWh/year)	**862.1**	**1872.6**	**683.5**	**1170.3**	**660.5**	**1201.9**
TOTAL (kWh/year)	**2734.7**		**1853.8**		**1862.4**	

Solution 2 and solution 3 are clearly more efficient than solution 1. Although the macro-components were selected in order to have similar thermal transmittance coefficients, the thermal inertia of the solutions is quite different. The energy need for domestic hot water (DHW) production is the same for all solutions, since it´s only dependent on climate, building function and conditioned area.

Comparison between the three constructive solutions in the concept stage

From the analysis of the results of the life cycle assessment (seven impact categories) plus the indicator of energy needs of the building for space heating and cooling it is hard to realise which is the most beneficial solution, i.e., the solution with lower life cycle impacts and lower energy demands. Therefore, multi-criteria analysis is performed in order to rank the alternative solutions. PROMETHEE II (Brans and Mareschal 2005) is used and the three alternative building solutions are analysed against the eight criteria referred above.

In order to use PROMETHEE II, two main steps are needed: (i) the selection of weighting factors for different criteria, and (ii) the selection of the preference function and respective threshold for each criterion (Gervásio and Simões da Silva 2012).

In this case study, the Gaussian criterion is selected, in which the preference function is monotonically increasing for all deviations and has no discontinuities (preference function type VI). The threshold value of this preference function defines the inflection point of the curve. Hence, considering the same importance (equal weighting factors) and preference function type VI for all criteria, the ranking of alternatives, given by the balance between the positive and negative outranking flows (Gervásio and Simões da Silva, 2012), leads to the results indicated in Figure 26. The higher rank, meaning the most beneficial solution among the alternatives, is obtained by solution 1, followed by solution 3 and solution 2 in decreasing order.

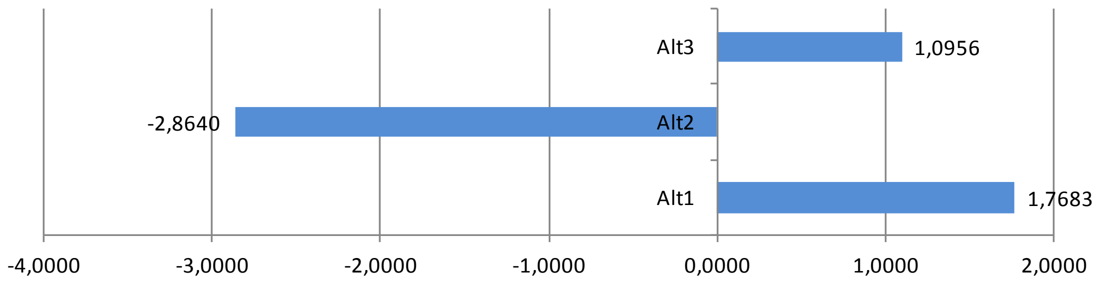


Figure 26. Ranking of solutions considering the same importance for all criteria (concept stage).

Assessment in the preliminary stage of design

The availability of data in the preliminary stage of design is usually higher than in the previous stage. In this case study, it is assumed that the main plans of the building are already known as described in the following sections.

Geometry and envelope

The façades and the horizontal plans of the building are provided in Figures 27 and 28, respectively.

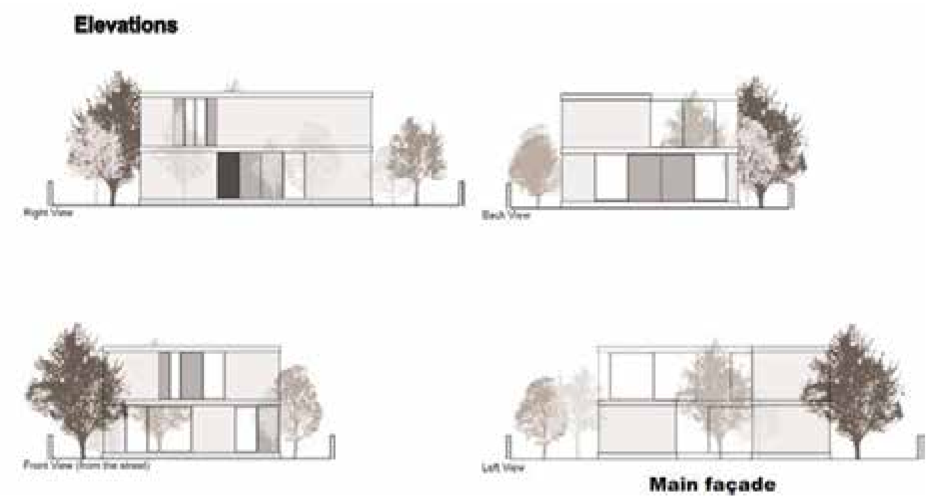


Figure 27. Façades of the case building.

The total area of construction is about 202.00 m^2, with 100.8 m^2 on the ground floor and 100.8 m^2 on the first floor (20.2 m^2 in terrace). The total height of the building is 6 m. The main façade of the building, indicated in Figures 7 and 8, is considered to face west.

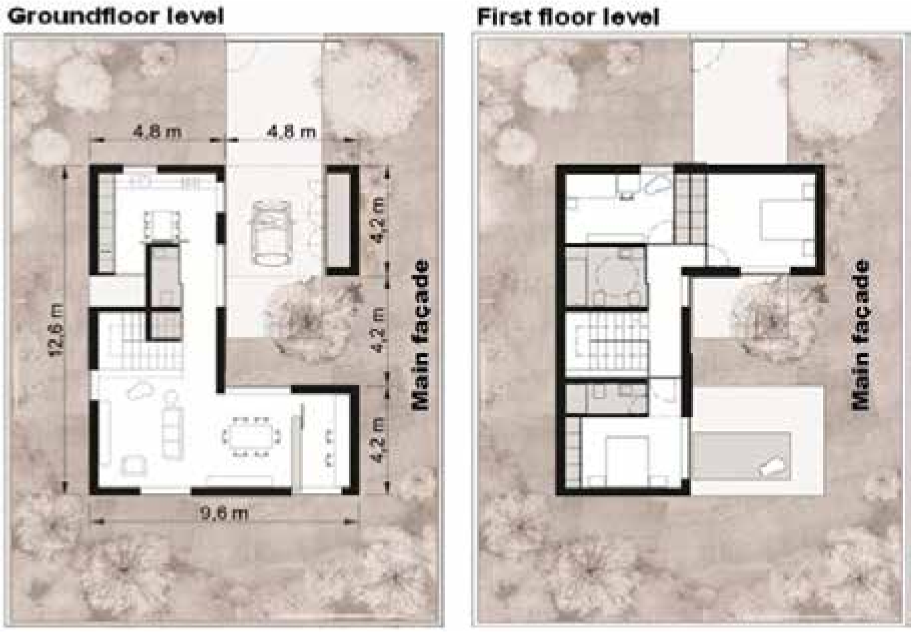


Figure 28. Floor plans of the case building.

The glazing areas of each façade are also provided in the plans of the building. Table 29 summarizes the areas of the building envelope.

Table 29. Walls and glazing areas in the preliminary stage.

	North [m^2]	East [m^2]	South [m^2]	West [m^2]	Sum [m^2]
Walls	41.3	49.9	38.3	60.4	189.9
Glazing	13.0	17.3	15.6	4.3	50.2

Additional macro-component for the slab above the garage

In the preliminary stage, the same macro-components are considered for the building envelope. However, an additional macro-component assembly is needed for the slab above the garage.

Data needed for the quantification of the operational energy

Although in this stage further project details may be already available in relation to the use of equipment for heating and cooling, for the purpose of this case study, the same parameters considered for the concept stage are taken this stage. Therefore, no further details are herein provided.

Environmental life cycle analysis

According to the building geometry previously presented in Figures 27 and 28, and by the use of selected macro-components, the environmental calculations are undertaken for the complete building and for a life span of 50 years. The results were similar with the concept stage of design so that the construction stage (modules A1–A3) dominates all impact categories (with contributions higher than 60%). Likewise, the remaining stages have similar importance as in the previous analysis.

The results for the three solutions are summarized in Table 30. As already observed in the concept stage, Solution 1 has a better performance for environmental categories of ADPfossil, EP and GWP; Solution 3 has a better performance for environmental categories of AP, ODP and POCP; and Solution 2 has a better performance only for environmental categories of ADP elements.

Table 30. Life cycle environmental analysis of the three alternative building solutions, in the preliminary stage.

Concept stage	Solution 1	Solution 2	Solution 3
ADP elements [kg Sb-Equiv.]	1.11E-01	5.00E-02	1.72E-01
ADP fossil [MJ]	4.38E+05	7.12E+05	6.06E+05
AP [kg SO2-Equiv.]	1.35E+02	1.48E+02	1.26E+02
EP [kg Phosphate-Equiv.]	1.53E+01	1.98E+01	1.94E+01
GWP [kg CO2-Equiv.]	3.54E+04	7.21E+04	7.24E+04
ODP [kg R11-Equiv.]	1.00E-03	1.14E-03	5.05E-04
POCP [kg Ethene-Equiv.]	3.71E+01	4.35E+01	2.44E+01

Operational energy quantification

The energy need for space heating and cooling in the preliminary stage, for the three different solutions, is presented in Table 31.

Table 31. Energy needed for heating and cooling in the preliminary stage.

	Solution 1		**Solution 2**		**Solution 3**	
	$Q_{H,nd}$	$Q_{C,nd}$	$Q_{H,nd}$	$Q_{C,nd}$	$Q_{H,nd}$	$Q_{C,nd}$
JAN	263.2	0	281.2	0	222	0
FEB	181.3	0	139.2	0	135.2	0
MAR	115.6	0	67	0	62.5	0
APR	80.6	0	1.7	0	0	0
MAY	0	0	0	0	0	0
JUN	0	399.4	0	149.3	0	168.6
JUL	0	568.1	0	414.3	0	427.4
AUG	0	495.5	0	353.9	0	366.3
SEP	0	387	0	198.1	0	216.4
OCT	0	0	0	0	0	0
NOV	156.1	0	105.5	0	101.3	0
DEC	221.6	0	232.3	0	181.9	0
TOTAL (kWh/year)	1018.5	1849.9	826.9	1115.7	702.9	1178.7
TOTAL (kWh/year)	2868.4		1942.6		1881.3	

In this case, solution 3 has a slightly advantage in relation to solution 2, while solution 1 remains the worst solution. Likewise, the energy need for domestic hot water (DHW) takes the value of 2642.6 kWh/year, for the three solutions.

Comparison between the three constructive solutions in the preliminary stage

Following the same approach as described for the concept stage, a multi-criteria analysis is performed in order to rank the three solutions. Considering the same importance and preference function type VI for all criteria, the ranking of solutions is indicated in Figure 12. In this stage, the same ranking of solutions is obtained, that is, the higher performance is obtained by solution 1, followed by solution 3 and solution 2 in decreased order.

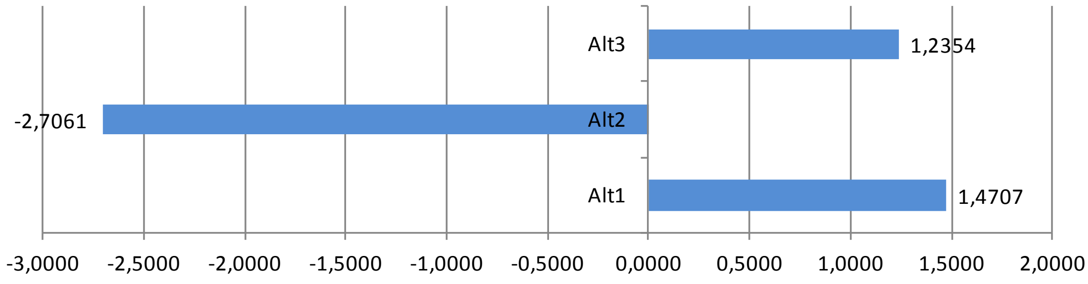


Figure 29. Ranking of solutions considering the same importance for all criteria (preliminary stage).

Benchmarking with a commercial software

The case building with construction solution 1 (the light-weight steel framed building) was analysed taking into account full building details and life cycle stages. The plans and building details used in this section are the ones presented for the preliminary stage.

The main goal of this analysis is to compare and verify the accuracy of the simplified approach described before and to quantify the importance of the aspects that are not covered in the macro-components approach.

Life cycle analysis

The life-cycle analysis herein presented aims to fill the gaps in the macro-component approach described previously, namely the foundations of the building and the construction stage (module A5). The full life cycle analysis was performed by GaBi 6 software (2012).

The foundations of the building are in reinforced concrete and the first level of the building is elevated about 50 cm from the ground base. At the end-of-life, reinforced concrete is recycled assuming the same recycling rates as in the preliminary stage for concrete and steel reinforcement. The construction stage (module A5) takes into account the following processes: (i) the preparation of the terrain (excavation of soil and transport to deposit) and (ii) the construction process (use of construction equipment for the assemblage of the structure and a forklift for the lifting of the structural panels). The construction of the building was considered to take 1.5 months. Hence, the life cycle analysis, taken into account all the life cycle stages, is represented in Figure 30.

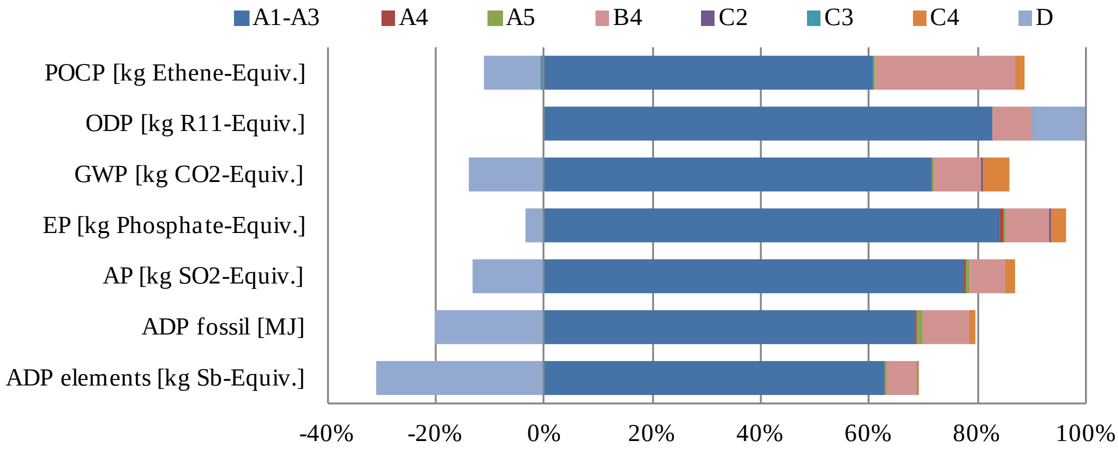


Figure 30. Life cycle analysis of a full building solution 1.

The construction stage (modules A1-A3) dominates all impact categories (with contributions higher than 60%). The construction stage (modules A4-A5) has a negligible importance, varying from 0%, for the categories of ODP, POCP and ADPelements to about 2.1% for the environmental category of ADPfossil. The stage of operation (module B4) and the recycling and recover of materials (module D) have a significant contribution to most impacts categories, followed by the demolition stage (modules C2–C4). It is noted that these conclusion were already achieved in the macro-components approach, despite its limitations.

Finally, the relative error in each impact category, of the macro-components approach in relation to the complete analysis is indicated in Table 32.

Table 32. Error (%) in each impact category by the use of the macro-components approach.

ADP elements	ADP fossil	AP	EP	GWP	ODP	POCP
0.0%	-2.4%	-1.3%	-1.3%	-1.3%	-0.1%	-0.5%

For most environmental categories the error is negligible. Therefore, despite the limitations of the macro-component approach, the results obtained by the proposed methodology led to the same conclusions as the full life cycle analysis.

Advanced dynamic simulation for energy calculation

The advanced dynamic simulation of the thermal behaviour of the building was performed using the DesignBuilder (2012) software. The source of weather data used in the simulation was the same as in the simplified approach for early stages of design. However, in this case, instead of monthly values for dry bulb temperature and solar radiation, hourly values are used for all the weather parameters.

The three-dimensional advanced modelling allows to simulate the full building architecture illustrated in Figures 17 and 18, for the preliminary design stage. Hence, Figure 31 illustrates two exterior elevation views of the DesignBuilder model used in the dynamic simulation. The building model was assembled using ten different thermal zones, corresponding to the internal partitions of the building (Figure 32): (i) the crawl space on the basement, which was modelled as an unconditioned space; (ii) the ground floor, which has three thermal zones; (iii) the first floor with five zones; and (iv) the area that is common to both floors, which includes the corridors and the stairways.

a) Southern and western views

b) Northern and eastern views

Figure 31. Elevation views of the building model.

The construction elements considered in the model are the same as described previously for the macro-components approach for constructive solution 1. Likewise, the same strategy for windows shading control was considered. In addition, the occupancy schedule, the ventilation and infiltration rates, the efficiency and the schedule of the air-conditioning equipment are taken from the previous analysis.

The main difference between the numerical analysis and the simplified approach is related with the internal heat gains. Instead of default values per area (in W/m2), as indicated in Table 9, in the advanced approach the internal heat gains were computed taking into account the number of estimated persons in each compartment (occupancy density) and their metabolic activity. The heating and cooling set point temperatures are the same (20 °C and 25 °C, respectively). However, in the numerical analysis set-back temperatures are defined in order to avoid extreme temperatures inside the building. In this case, the set-back temperatures for heating and cooling modes are 16 °C and 31 °C, respectively. A graphical comparison between the monthly and annual energy needs, for heating and cooling, computed by both approaches for construction solution 1, is displayed in Figure 32.

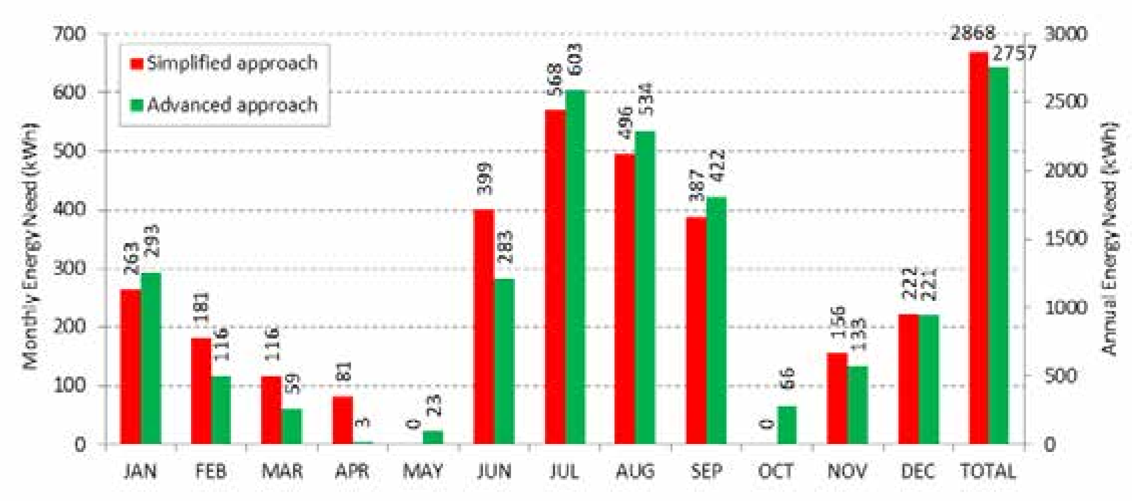


Figure 32. Comparison of energy needs for space heating and cooling.

Is was observed that there is a fair agreement between both approaches. Taking as reference the values of the advanced approach, the value of the energy need for space heating in the simplified approach has an error of +23%. On the other hand, the value of the energy need for space cooling in the simplified approach has an error of -4%. Taking into account the balance per year, the annual average error provided by the simplified approach is about +4%. The numerical simulation herein presented had a comparative purpose and therefore, the values for the use of equipment were taken from the simplified approach. As a result, it is noted that the values for energy heating and cooling of the building are not necessarily optimized.

2.5 Case Studies (WP 5)

2.5.1 Summary of selected cases

The work was started in 2011 and continued throughout 2012. A list of possible case studies that fulfil requirements of available data is presented in Table 33.

Table 33. List of potential case studies.

Partner	Type of building	Type of main load bearing structure	City	Country
AUTH	Industrial steel building	Hot rolled	Thessaloniki	Greece
ACCIONA	House	Prefabricated one-way slabs supported by portals made of reinforced concrete pillars	Gran Canaria	Spain,
	Multi-storey building living	Concrete structure reinforced	Ceuta	Spain
	Multi-storey building offices	Walls, beams and reinforced concrete columns supply, prefabrication and installation of carbon steel profiles. Metallic structure for all types of structures, including triangulated trusses and beams.	Luanco-Gozón	Spain
	Multi-storey building offices		Huelva	Spain
TECNALIA	Rehabilitation of a multi-storey building, structural refurbishment of educational building	Hot rolled steel	Bilbao	Spain
	Façade energy retrofitting, renovated with steel sheets and insulations	Concrete	Asturias	Spain
	Rehabilitation of a historical building, structural refurbisment	Mainly hot rolled but also used cold formed and composite structure		Spain
PUT	Multi-storey building residence-Arghirescu	Hot rolled	Timisoara	Romania
	Multi-storey building -offices	Hot rolled with composite steel concrete columns	Constanta	Romania
	House-Bulzesc	Cold formed	Timisoara	Romania
	House-Carmen	Hot rolled with wood floors and roof		Romania
	House-Constantin	Cold formed	Ploiesti	Romania
	House Pascut	Hot rolled	Timisoara	Romania
FCTUC	House	Cold formed	Coimbra	Portugal

Following this list a set of case studies has been selected for further analysis:

- Steel intensive hot rolled apartment building – Romania
- Steel intensive hot rolled office building – one from Romania and other from France (added after the ending subtask 1.3.3.)
- Steel intensive cold formed house one from Romania and other from Portugal
- Steel intensive hot rolled house – Romania
- Rehabilitation of multi-storey building and of a market both cases from Spain

Creation of data bank of all case-studies

After being set the case studies that should be analysed, it was proceeded to gather and organise all the information necessary for obtaining a complete data base:

- Overall description of the case studies (a summary of information regarding of the site location, environmental conditions, restrictions of the region and beneficiary requirements)
- Architectural information (drawings, descriptions, pictures).

All the information has been uploaded to the VTT workspace so that all the partners can have access to them and to encourage further discussions.

2.5.2 Reference design of the case studies (T5.2)

A small number of cases was selected for which the architectural and structural design was made in detail. These are shown in Table 34.

Table 34. Reference design of buildings for the case studies.

Building typology		
Low-rise residential	Multistorey residential / office	Renovation
Reference design		
TUTI and UC	TUTI	Tecnalia

For the case studies presented above the data base described at the subtask 5.1.2 has been update with the following information:

- Structural design information (drawings, calculations)
- List of materials and quantities for the entire structure
- Energy efficiency analysis
- Pictures from the site

All the structures were organised into macro-components according to the provisions from the Work Package 2 for a better organising and understanding of the layers.

The data was used for providing the environmental and energy-related data for macro-components.

2.5.3 Localization of the case studies for the var. climatic regions (T 5.3)

The databank of buildings and macro-components was complemented through new cases and through adapting the Romanian cases to Northern and Southern design conditions. The set of cases consisted finally from the cases presented in Table 35.

Table 35. Climates in which building cases located.

	Building typolology		
	Low-rise	Multi-storey	Renovation
	Localization to climatic region		
Northern	TUTI+VTT	TUTI+VTT	VTT
Central	TUTI	TUTI+Mostostal	TUTI
Southern	UC	TUTI+AUTH ArcelorMittal	Technalia

All the building cases were organised to macro-components. The environmental and energy-related indicators were calculated for the functional unit of 1 m^2 of each macro-component. The software used was SimaPro for which the “Politehnica” University has acquired a license.

The models contain 3 main stages in the life of macro-components:

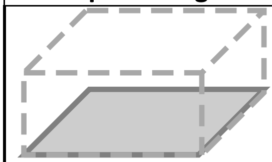
Production Stage=>Use Stage=>End of Life stage

The use stage depends on the practices used in each region for maintenance and all the partners involved were required to give a list of provision for each case study in order to introduce them into the software. The same was required for the end of life process due to the fact that they depend on the country/town view and practices towards selective waste collection and their capacities for recycling in a safe and environmental friendly manner. The production stage was easiest to add in the software but the use stage and end of life are mode subjective.

A set of case-studies covering residential (low rise and multi-storey) and office buildings have been selected as a base for identifying the needs for the new developed SB_TOOL software as it was presented in deliverables D5.1 and D5.2. More, those case studies have been calculated for various regions in Europe (see Table 35) in order to identify the requirement in various climatic regions and the best design practice in the selected countries and were based on full design of the buildings.

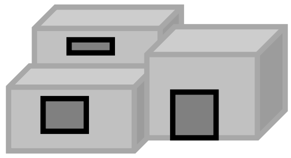
Based on these case studies we took a top-down approach in order to identify the data that will be needed in the early stages of design (conceptual design and preliminary design). In order to see the differences between these stages an explanatory table is indicated below (Table 36 and 37).

Table 36. Input data at the conceptual stage.

INFORMATION DETAILS IN EACH STAGE OF THE BUILDING			**Conceptual stage** 
Type of building (occupation)	residential/office low/medium/high rise		Yes
Location data	Location of building		Yes
	Climatic characteristics		Yes
	Air quality		Maybe
	Geotechnical data		Maybe
Architectural	Total area of building		Yes
	Area of floors		estimation
	Height of floors		Yes
	Area of external walls		estimation
	Area of internal walls		estimation
	Area of roof		estimation
	Area of fenestration		estimation
	Horizontal plans of building		No
	Vertical plans of building		No
Structural data	Type of load-bearing structure		Yes
	Materials characteristics		estimation
	Safety requirements		No
	Detail design		No
	Bill of materials		No
Functional data	Building orientation		No
	Details of layers	external walls	estimation
		internal walls	estimation
		floors	estimation
		roof	estimation
	Thermal characteristics	external walls	estimation
		internal walls	estimation
		floors	estimation
		roof	estimation
	Acoustic characteristics	external walls	estimation
		internal walls	estimation
		floors	estimation
		roof	estimation

	Glass characteristics of windows	estimation
	Frame characteristics of windows	estimation
	Lighting installation and daylight	estimation
	Ventilation system	estimation
	Heating system	estimation
	Cooling system	estimation
	Domestic hot water production	estimation
	Internal loads	estimation

Table 37. Input data at the pre-design stage.

INFORMATION DETAILS IN EACH STAGE OF THE BUILDING		**Preliminary stage** 
Type of building (occupation)	residential/office low/medium/high rise	Yes
Location data	Location of building	Yes
	Climatic characteristics	Yes
	Air quality	Maybe
	Geotechnical data	Yes
Architectural	Total area of building	Yes
	Area of floors	Yes
	Height of floors	Yes
	Area of external walls	Yes
	Area of internal walls	Yes
	Area of roof	Yes
	Area of fenestration	yes
	Horizontal plans of building	maybe
	Vertical plans of building	maybe
Structural data	Type of load-bearing structure	yes
	Materials characteristics	yes
	Safety requirements	yes
	Detail design	estimation
	Bill of materials	estimation
Functional data	Building orientation	yes
	Details of layers of external walls	yes
	Thermal characteristics of external walls	yes
	Acoustic characteristics of external walls	yes
	Details of layers of internal walls	yes
	Thermal characteristics of internal walls	yes
	Acoustic characteristics of internal walls	yes
	Details of layers of floors	yes
	Thermal characteristics of external floors	yes
	Acoustic characteristics of floors	yes
	Details of layers of roof	yes
	Thermal characteristics of roof	yes
	Acoustic characteristics of roof	yes

	Glass characteristics of windows	yes
	Frame characteristics of windows	yes
	Lighting installation and daylight	yes
	Ventilation system	maybe
	Heating system	maybe
	Cooling system	maybe
	Domestic hot water production	maybe
	Internal loads	maybe

Finally, all case studies presented above were run using the developed software, i.e. SB_TOOL, and were shown in detail in deliverable “SB_Steel Software Design Example”.

2.5.4 Workshop on case studies (T5.4)

3rd Workshop was organised in Timisoara on 29th of January, 2013. Before, papers were prepared that included relevant building design and climatic information and the results of environmental and energy-related calculations. The environmental indicators were calculated in Timisoara except for the Coimbra case (UC) and the French case. The energy consumption was calculated by each beneficiary involved. The Proceedings of the Workhop includes all the case studies.

2.6 Dissemination, public consultation, recommendations and background documents (WP 6)

Work Package 6 dealt with the dissemination and public consultation concerning the results of the research project.

2.6.1 Communication and consultation in organisations where partners are represented (T6.1)

In order to cover a wide scope in regard to the communication of the results of the project to organisations of importance to the steel construction sector, a list was compiled by the task leader containing organizations/forums/associations etc. in which SB_Steel partners are involved. This list was completed by all the partners and verified for sufficiency, covered scope and possible additions. A number of organisations were mentioned, eg. VTT in CEN TC350 and SB_Alliance, Luis Braganca is the President of iiSBE, Heli Koukkari is a member of ESTEP WG3. Other contacts include other activities like EU-projects (OpenHouse/ Acciona plus experts, Superbuildings/ VTT, Cileccta/ Acciona, Lense, Building Up/ Heli Koukkari as an expert). The contact list was used for search of keynote speakers to and advertising of Workshops. Presentations of the SB_Steel project were also given in the meetings of the other organisations (iiSBE, ECCS TC14, ESTEP).

The Workshop 1 was organised in co-operation with ECCS as a side-event of the EuroSteel Conference in Budapest. The Workshop 2 was organised in co-operation with ECCS and ESTEP WG3. Keynote speakers were from Worldsteel Association, Eurofer, FOSTA and BauforumStahl among others.

2.6.2 Editing of a technical booklet (T6.2)

Task 6.2 produced a technical booklet based on design examples that were used to support and test the software. The design examples were planned according to the same climatic zones as the case studies. The building data inputs were also the same as in case studies.

The most appropriate case studies that effectively display the usage and potential of the SB-Steel software were selected for inclusion in the case study booklet. Some of the design examples were presented completely showing the different stages of the software and its use, some were only showing the report that the software send to a user's e-mail. The full example is introduced below concerning the French case reported by University of Minho.

Introduction for use of the software

In order to perform an assessment with SB_Steel tool some data of the building is required. Notwithstanding, if having some doubts of which construction solution to choose, or which heating system it will have, the tool allows you to assess a solution first, and then the other, presenting and comparing the results of both at the end. Like this you will be able to know which solution has a better performance, adding therefore the design decision-making process.

The tool allows you to perform a conceptual or pre-design phases assessment (stage of the assessment), considering different life cycle stages (scope of the assessment): (i) cradle-to-gate analysis (Module A); (ii) cradle-to-gate + end-of-life recycling (Module A + Module D) and; (iii) cradle-to-grave + end-of-life recycling (Module A to Module D).

The data needed for an assessment with SB_Steel Tool is summarised in Table 38.

Table 38. Building data required for the software.

Climatic data	Köppen–Geiger climatic type	
	City	
Building type	Type of main structure and main function of the building (single-family, office building, etc)	
Macro-components	Roof floor	Roof decks, slabs and sheathing
		Roof structural frame
		Ceiling finishes
	Interior floor	Flooring
		Floor structural frame
		Ceiling finishes
	Ground Floor	Flooring
		Floor structural frame
	Exterior wall	Ext. wall veneer
		Ext. wall construction
		Wall finishes
	Interior wall	Int. wall A
		Interior partitions
Type of Analysis	Stage of the Analysis	
	Scope of the Analysis	
	Lifespan of the Analysis (years)	
Building Area	Building orientation	
	Dimension (width x length)	
	Height	
	Number of floors	
	Area glazing north, south, east, west (%)	
Indoor conditions	Heating set point	
	Cooling set point	
	Air Flow rate, heating	
	Air Flow rate, cooling	
Building energetic system	Heating system	
	Cooling system	
	Renewable electricity production (kWh/year)	
	DHW system	
	Renewable energy – for DHW use	
	Ventilation type	
	Heat recover	
Operational specifications	Glass type	
	Glazing frame	
	Shading device	
	Colour of opaque envelope (light, dark)	
	Ground floor type	
	Soil type	

After the assessment the results will be presented and sent by e-mail if desired. The results obtained are:

- Energy needed for space heating;
- Energy needed for space cooling;
- Energy needed for DWH production;
- Solar heat gains;
- Environmental impacts from the whole building and by macro-component.

If alternative solutions are introduced for assessment, after the results, the tool will provide a chart showing the solution with better performance.

DESIGN EXAMPLE APPLICATION

The description of this case study was made an example for testing the SB_Steel software. The assessment is divided in eight steps, each one corresponding to the data needed presented in Table 37.

Open SB_Steel Software

In order to start the assessment, open the internet browser and go to: http://onesource.pt/sbsteel/site/. Figure 33 illustrates the homepage of the methodology website that will appear on the screen.

Figure 33. Home page of SB_Steel.

Selection of climatic zone

The first step is to select the climatic zone corresponding to the building's location (Figure 34). The adopted classification system was the Köppen–Geiger climate classification. According to the image presented and its legend select one of the following four: Csa, Csb, Cfb or Dfc. In this case, as the building is located in France, the chosen area was Cfb. For that there is only need a mouse click on the corresponding legend.

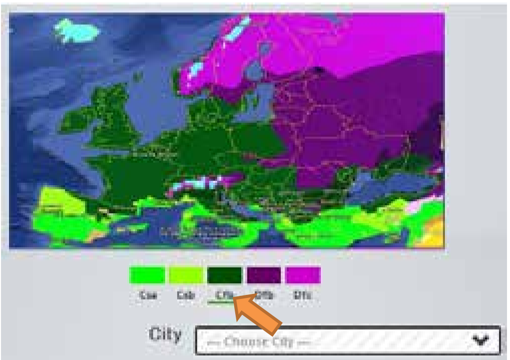


Figure 34. Selection of Climatic Zone.

Then, the city should be selected among the ones presented (Figure 35). In this case, the chosen city was Paris.

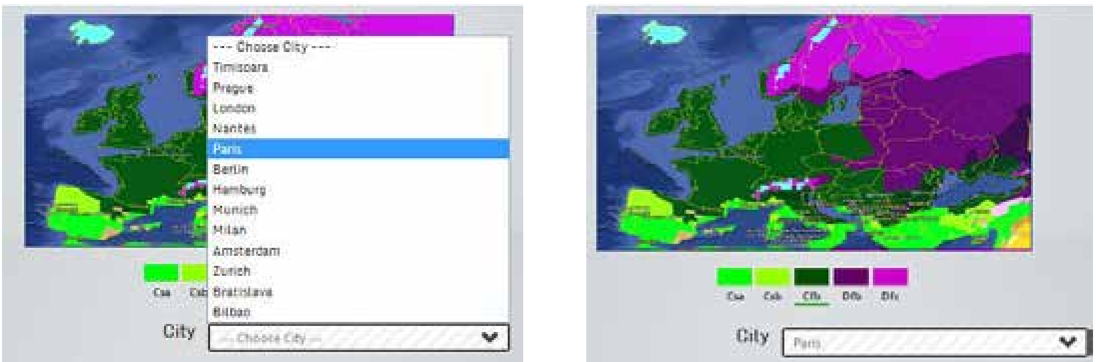


Figure 35. Selection of the city.

Then press "next" button and go to the next step.

Selection of building's typology

This step consists in selecting the building's typology. Each column corresponds to a category related to the main structure of the building:

- Category 1: Steel intensive building in which the main structure (frame and metal floor decking) and sub-structure (foundations and sheet piling) are made of steel components;
- Category 2: building in which the main structure is not made of steel but other components such as the envelope (roofing and wall cladding), is made of steel;
- Category 3: building in which only secondary components such as service ducting, furnishings, fittings and finishes are made of steel.

Each row corresponds to the buildings typology: low-rise family (single or multi) building, multi-story/apartment block, office building and commercial/Industrial buildings (Figure 36).

Figure 36. Main page of selection of building type.

In this case, the selection made corresponds to a steel intensive office building. Just click on the image corresponding that corresponds better to your building typology.

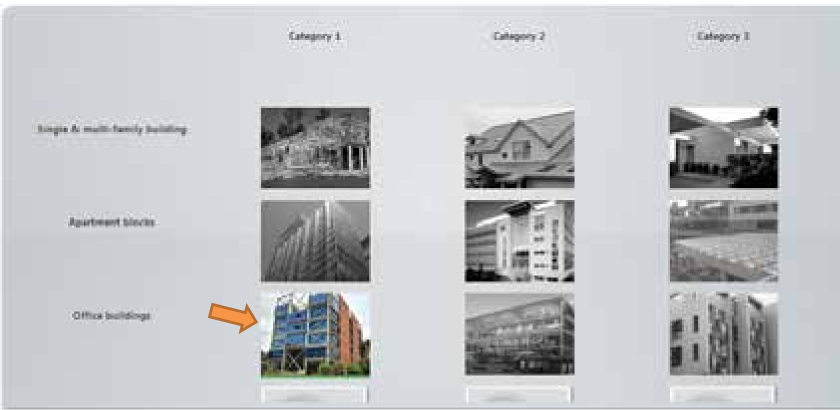


Figure 37. Selection of building type (category 1; office building).

After selecting the building type, all images are black & white, while the selected option is in colours.

"Next" button shall be pressed to go to the following step.

Selection of Macro-Components

This step is aimed to identify the main solutions foreseen to be used in the buildings elements. In this sense it is sub-divided in five steps:

- Macro-components of roof floor;
- Macro-components of interior floor;
- Macro-components of ground floor;
- Macro-components of exterior wall;
- Macro-components of interior wall.

The tool comprises a database with different macro-components solutions, so there is only need to select the one that best feats the solution to evaluate, and determine the thickness of the different materials. If desired the assessment can be made with default thickness values. Also, inertia and heat transfer coefficient can be changed or kept with default values.

Macro-components of roof floor

The description of the roof floor macro-component comprises the identification of the roof decks/slabs, structural frame and ceiling finishes.
After selecting the options desired, the thickness of the materials can be changed or left with the default values.
For this design example the solutions selected were the ones presented in Table 39 and Figure 38 below.

Table 39. Detail of the building's roof floor macro-component.

Roof decks, slabs and sheathing	Option 1	Concrete slab (mm) – 30 XPS (mm) – 30 Air (mm) – 40 XPS (mm) – 30 Waterproof film (mm) – 1.63 Concrete screed (mm) – 180
Roof structural frame	Option 2	Composite slab h total (mm) – 150 Steel structure (mm) – 0.8 Gypsum Plasterboard (mm) – 25
Ceiling finishes	Option 1	Paint (mm) – 0.125

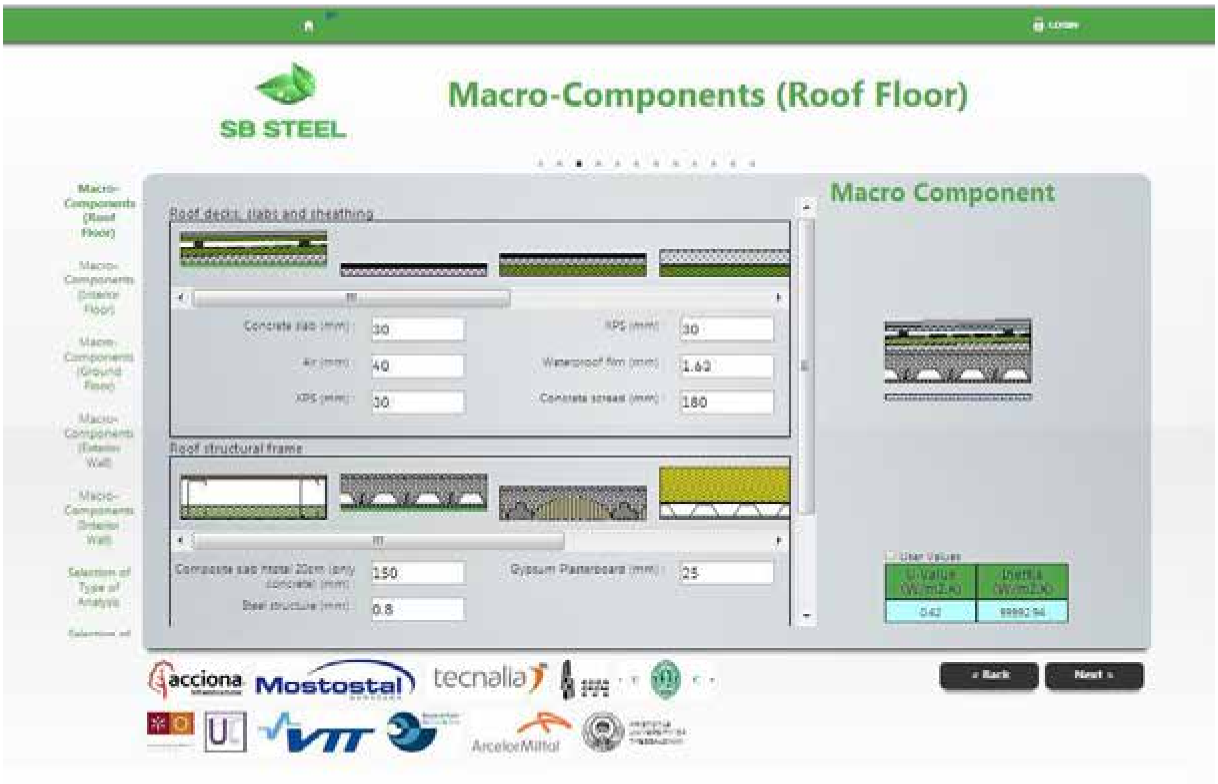


Figure 38. Building's roof floor macro-component identification.

Press "next" button to go to the next macro-component.

Macro-components of interior floor

The procedure is the same as the presented for the roof floor macro-component. The interior floor macro-component for the subject building is described in Table 40 and its identification in the tool is illustrated in Figure 39 below.

Table 40. Detail of the building's internal floor macro-component.

Flooring	Option 2	Parquet (mm) – 10 Concrete screed (mm) – 13
Floor structural frame	Option 2	Polyethylene foam (mm) – 180 Gypsum Plasterboard (mm) – 25 Composite slab htotal (mm) – 150 Steel structure (mm) – 0.8
Ceiling finishes	Option 1	Paint (mm) – 0.125

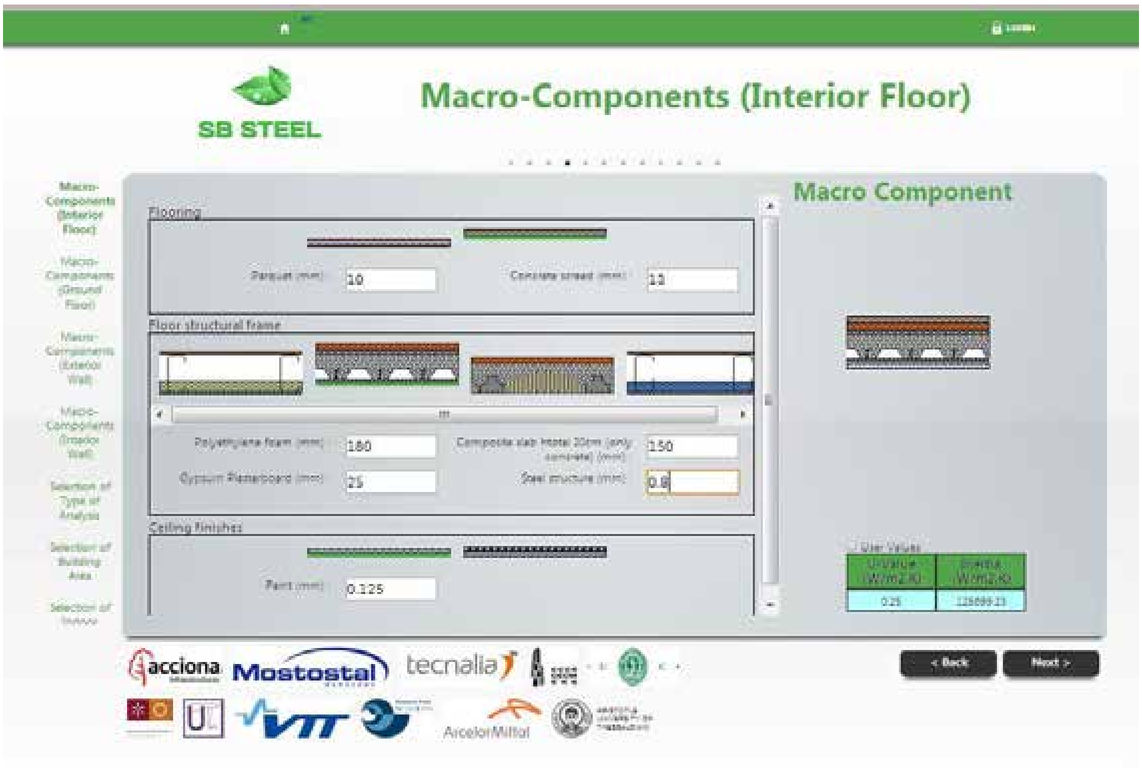


Figure 39. Building's internal floor macro-component identification.

Press "next" button to go to the next macro-component.

Macro-components of ground floor

The ground floor macro-component for the subject building is described in Table 40 and its identification in the tool is illustrated in Figure 40.

Table 40. Detail of the building's ground floor macro-component

Flooring	Option 1	Ceramic tile (mm) – 5.5 Concrete screed (mm) – 13
Floor structural frame	Option 1	slab pre-cast 18cm (hollow LWC bricks) (mm) – 150 XPS (mm) – 40 Filter fabric (polypropylene) (mm) – 0.2 Filter fabric (polypropylene) (mm) – 0.2 Filter fabric (polypropylene) (mm) – 0.2 Sand (mm) – 30 Gravel (mm) – 350

Figure 40. Building's ground floor macro-component identification.

Press "next" button to go to the next macro-component.

Macro-components of exterior wall

The exterior wall macro-component for the subject building is described in Table 41 and its identification in the tool is illustrated in Figure 41.

Table 41. Detail of the building's exterior wall macro-component.

Ext. wall veneer-	Option 2	Paint (mm) – 0.125 Cement mortar (mm) – 15
Ext. wall construction	Option 4	OSB (mm) – 15 Cold rolled steel (mm) – 0.8 OSB (mm) – 15 Gypsum Plasterboard (mm) –13 Air (mm) – 70 Rock wool (mm) – 100 Vapour barrier (mm) – 0.5
Wall finishes		Paint (mm) – 0.125

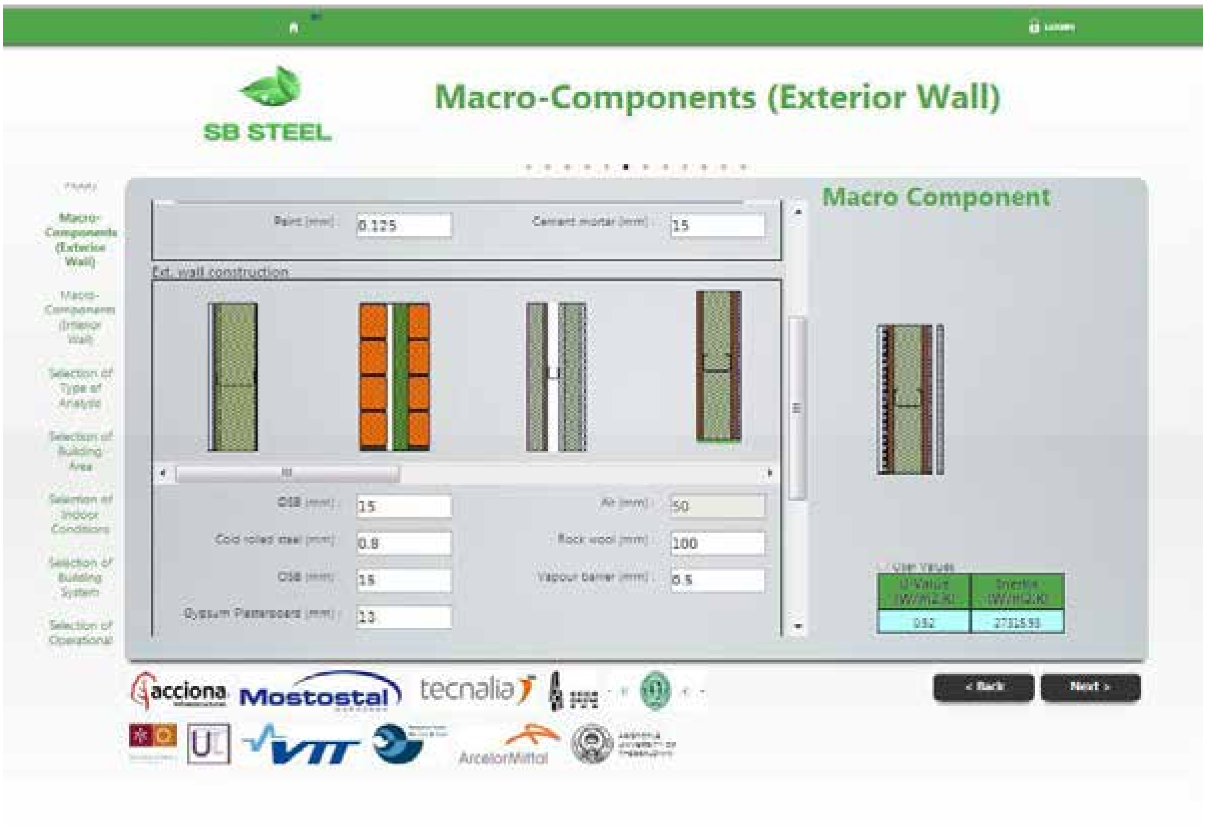


Figure 41. Building's exterior wall macro-component identification.

Press "next" button to go to the next macro-component.

Macro-components of interior wall

The last macro-component to describe is the interior wall solution. The building's interior wall macro-component is described in Table 42 and its identification in the tool is illustrated in Figure 42.

Table 42. Detail of the building's exterior wall macro-component.

Interior wall finish A	Option 1	Paint (mm) – 0.125
Interior partitions	Option 1	Gypsum Plasterboard (mm) – 10 Rock wool (mm) – 90 Gypsum Plasterboard (mm) – 10 Air (mm) – 0 Cold rolled steel (mm) – 0.8

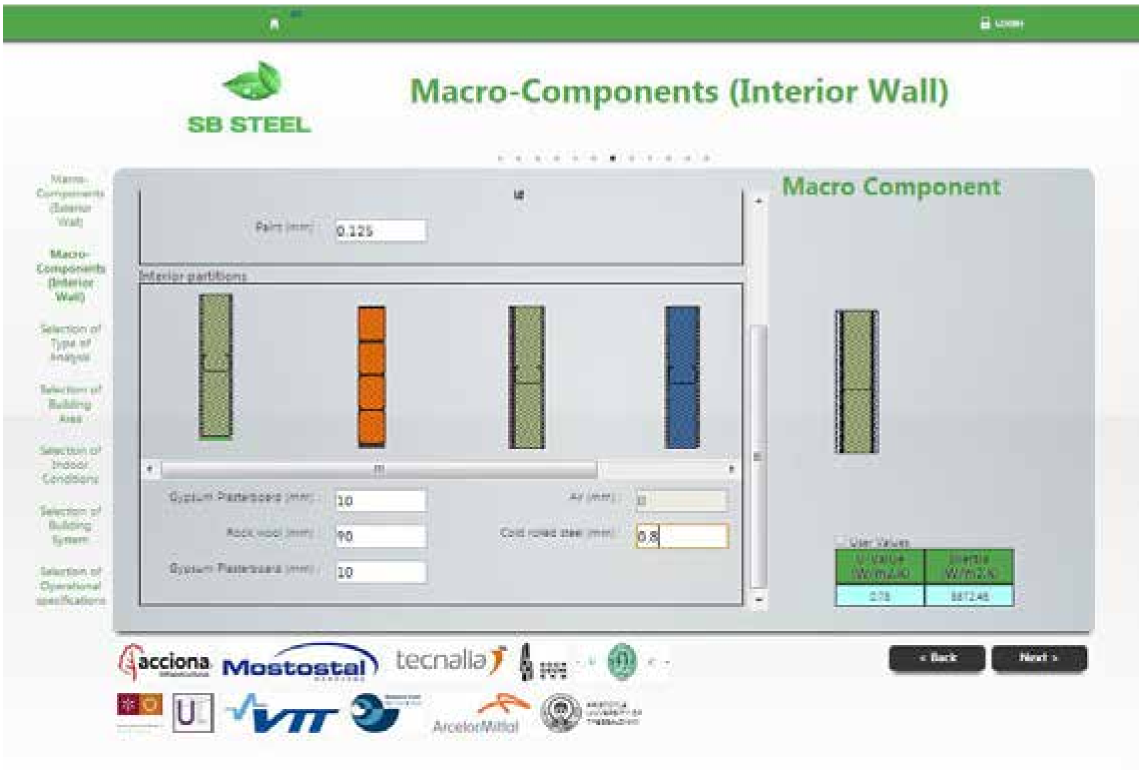


Figure 42. Building's exterior wall macro-component identification.

Press "next" button to go to the next macro-component.

Selection of the type of analysis

After the macro-components' input there is the need to select the type of analysis. This step entails three topics. In the first, one should select if the assessment is being carried out at conceptual or preliminary design phase. This will affect the detail with which the assessment is performed, as at preliminary design phase more data is available than at conceptual phase; for instance, building's dimensions or glazing areas are more accurate preliminary design.
The second topic regards the life-cycle phases that shall be included in the assessment. There are three possible options: (i) cradle-to-gate analysis (Module A); (ii) cradle-to-gate + end-of-life recycling (Module A + Module D) and; (iii) cradle-to-grave + end-of-life recycling (Module A to Module D). At last the desired lifespan of the analysis shall be stated in years (Figure 43).

Figure 43. Menu of selection of the type of analysis.

For this specific design example the three options were:

- Stage of the Analysis: conceptual phase
- Scope of the Analysis: cradle-to-grave + end-of-life recycling (Module A to Module D).
- Lifespan of the Analysis (years): 100

Figure 44 illustrates the specification of this information in the tool.

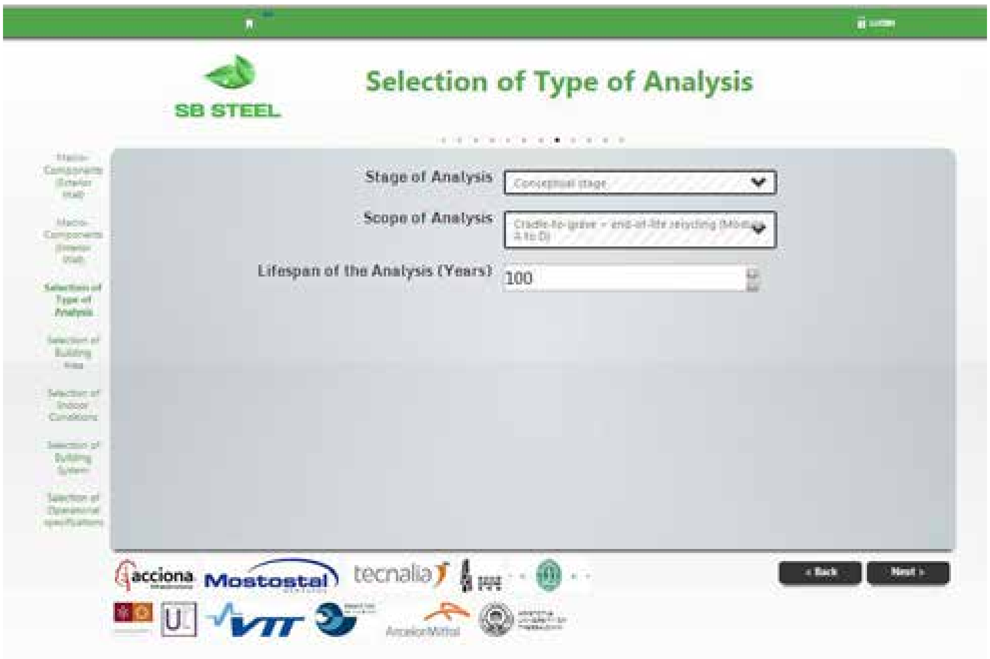


Figure 44. Selection of the type of analysis for the design example.

Selection of building area

In this step one shall be requested to identity the main building dimensions. It is important to mention that this step may differ if the stage of analysis selected previously was conceptual or preliminary design phase as shown in Figure 45. The difference between both is related to the building's geometry. While in conceptual phase, there are no specifications, probably only an expected length and width, in preliminary design this data tend to be more accurate and hence the building may have a different shape than the first defined.

(a) (b)

Figure 45. Menu of building's area selection; (a) menu presented when conceptual phase is selected, (b) menu presented when preliminary design is selected.

In this menu, one shall be requested to input the building's orientation and the details of its geometry: dimension (width x length), total height, number of floors and glazing area facing north, south, east, west.

In this design example, the specifications input in the tool were (Figure 46):

- Building orientation: south
- Dimension (width x length): 42 x 24 m;
- Height: 32.8 m
- Number of floors: 10
- Area glazing north: 17.7%
- Area glazing south: 17.7%
- Area glazing east: 17%
- Area glazing west: 17%

Figure 46. Illustration of the design example building's dimensions.

Selection of indoor conditions

Indoor conditions regard parameters related to the users' thermal comfort that influence the energetic calculations, as heating and cooling set points foreseen for the building's interior and the air flow rate both for heating and cooling.

In this design example, the specifications input in the tool were (Figure 47):

- Heating set point: 20 (default value)
- Cooling set point: 25 (default value)
- Air Flow rate, heating: 0.6 (default value)
- Air Flow rate, cooling: 1.2 (default value)

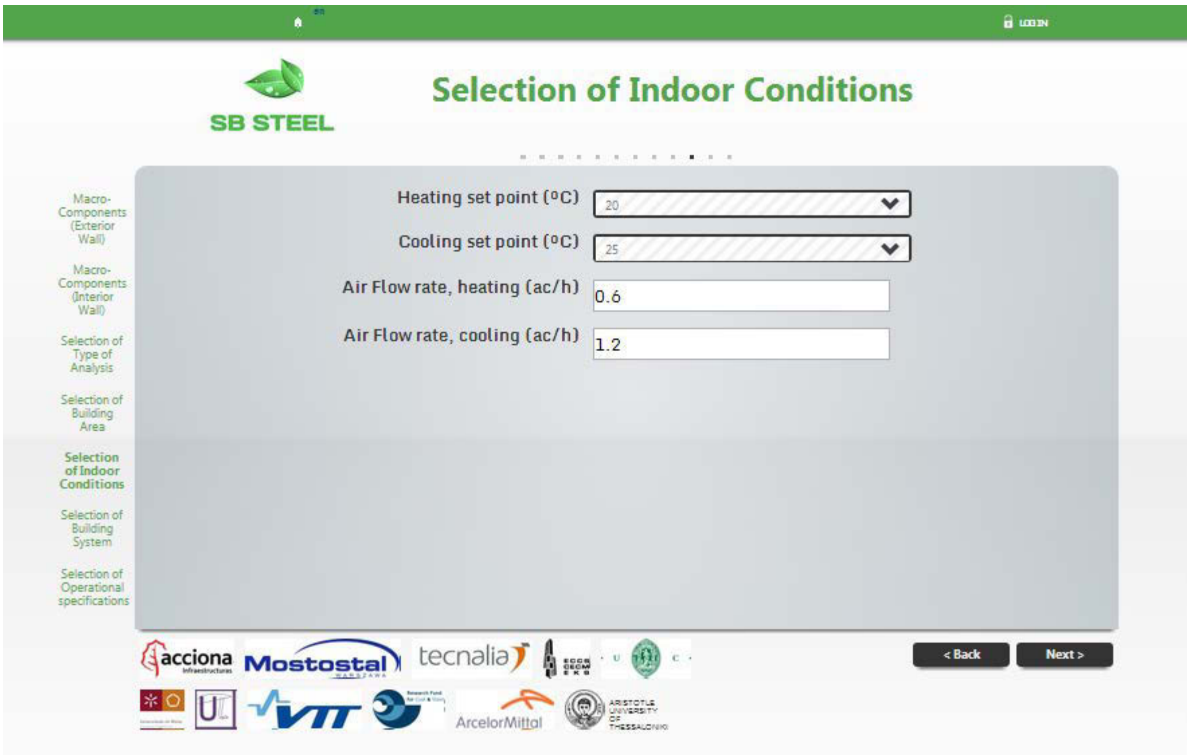


Figure 47. Illustration of the design example building's indoor conditions.

Selection of building energetic system

In this section it is intend for users to input the main description of the building's energetic system. If one may be in doubt about choosing one system at the end of the assessment a new alternative solution can be created in order to compare results.

The energetic system description consists in. (i) specifying the heating, cooling and Domestic hot water preparation (DHW) systems (heating: electric resistance, gas fuel heater, liquid fuel heater, solid fuel heater or slit; cooling: split, refrigerator machine – compression cycle, refrigerator machine – absorption cycle; DHW: electric boiler, gas boiler, stand-alone water heater (cont.) or stand-alone water heater); (ii) determining the existence of local electricity production and/or renewable energy for DHW and if yes, its estimated annual amount; (iii) the ventilation type (natural or mechanical) and, (iv) the existence of heat recover and if yes, its heat recovery efficiency rate.

In this design example, the specifications input in the tool were (Figure 48):

- Heating system: split
- Cooling system: split
- Renewable electricity production (kWh/year): 0
- DHW system: electric boiler
- Renewable energy – for DHW use: 0
- Ventilation type: mechanic
- Heat recover: no

Figure 48. Illustration of the design example energetic solutions.

Determination of operational specifications

Operational specifications recall aspects related to solar radiation absorption like glass type, glazing frame, shading device and colour of opaque envelope and related to ground floor and soil types. These aspects affect directly the energetic calculations.

In this design example, the specifications input in the tool were (Figure 49):

- Glass type: low emissivity U≤ 1.1 (U = 0.8)
- Glazing frame: aluminium

- Shading device: interior shutter intermediate
- Colour of opaque envelope: medium
- Ground floor type: basement
- Soil type: default

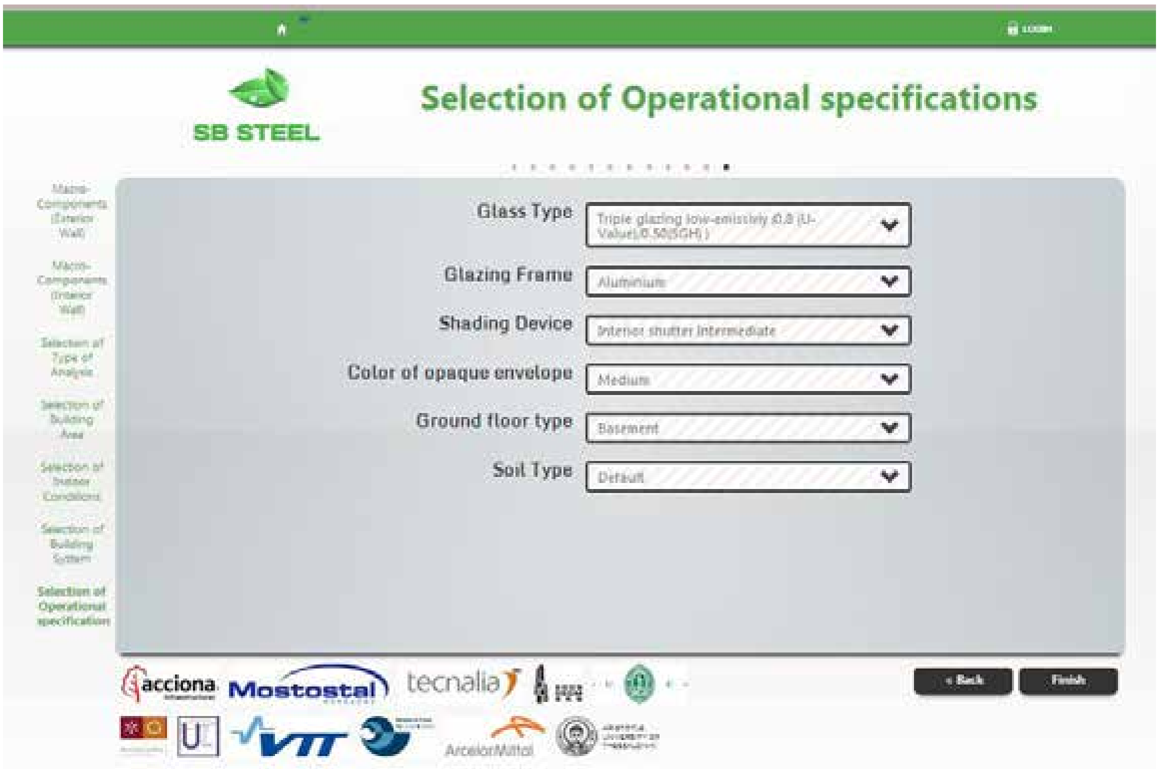


Figure 49. Illustration of the design example energetic solutions.

Press “finish” button to obtain the assessment results.

Results presentation

The assessment results are presented in both formats tables and charts. It starts with the energetic calculations presentation. Details on heating, cooling and DHW energetic needs are given as well as the solar gains. After that the environmental impact assessment is presented by building element (macro-component) followed by the whole building environmental life cycle impact.
Whenever desired, one can press the button “Report” and an e-mail address will be requested as to send the report to the given address (Figure 50).

Figure 50. Requiring report.

One can now finalize the assessment or press the button “add solution” if desiring to assess other building solution.

Figure 51. Adding a new solution.

If this button is pressed, the tool will drive the user back to the macro-components selection part. The procedure to follow from this point on is as already presented. At the end of the results presentation phase, a chart ranking the alternative solutions will be presented (Figure 52).

Figure 52. Illustration of alternative solutions comparison.

If not, results from the studied solutions can be viewed (Figure 53).

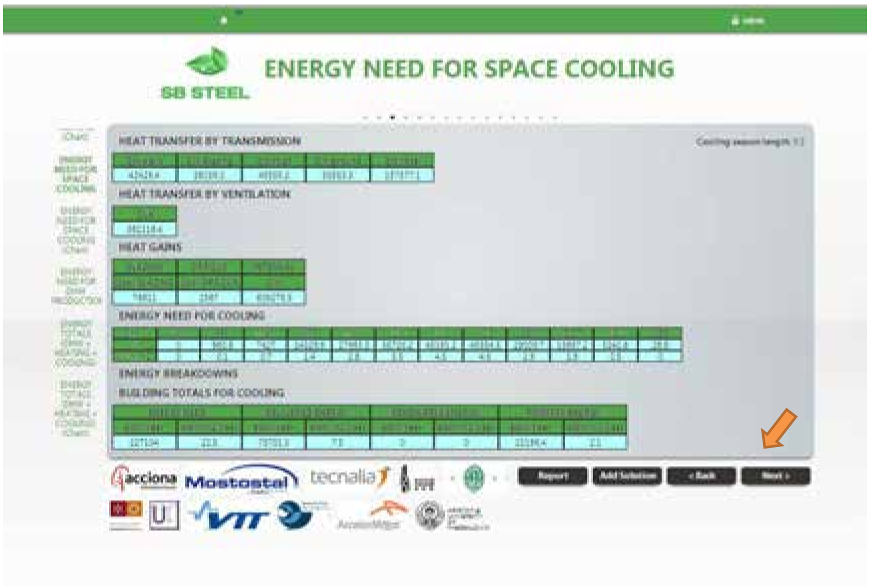


Figure 53. Requesting to view results.

First related energy results are presented and after are the environmental impact related ones. Results are shown in both table and chart formats. As usual, to go further with the results press “next” button.
Within energy, results start with the energy need for space heating (Figure), cooling (Figure) and DWH production (Figure 54). The table format for heating and cooling needs account results for:

- Heat transfer by transmission (walls, glazing, ground, roof and total);
- Heat transfer by ventilation;
- Heat gains (glazing, opaque and internal);
- Energy need for heating/cooling (each month);
- Building totals for heating/cooling (total energy needs, delivered energy, renewable energy and primary energy).

Chart format presents the heat/cooling transfer breakdown in percentage (walls, glazing, ground, roof and ventilation).
For the DWH the results account for:

- Energy need DWH preparation (each month);
- Building totals for DWH preparation (total energy needs, delivered energy, renewable energy and primary energy);

Figure 54. Results: Energy need for space heating.

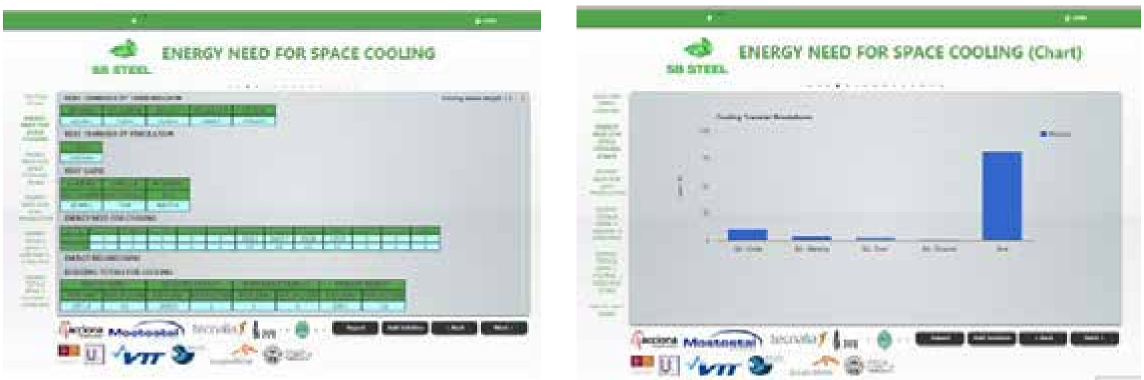


Figure 55. Results: Energy need for space cooling.

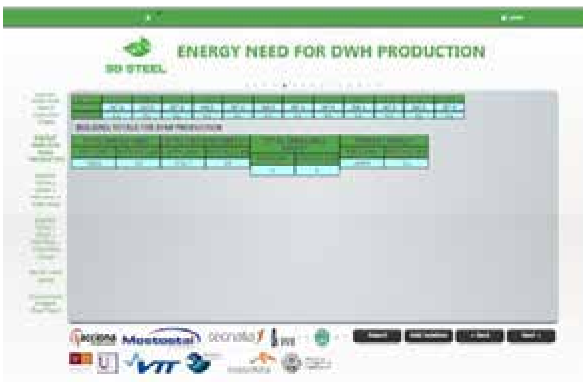
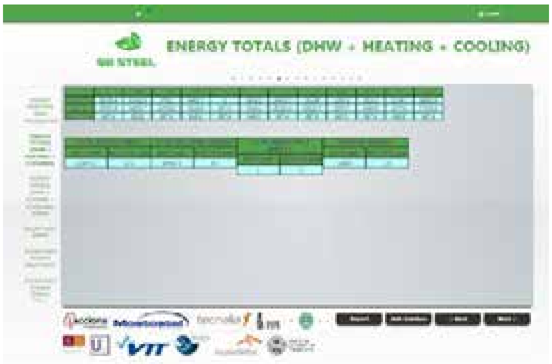
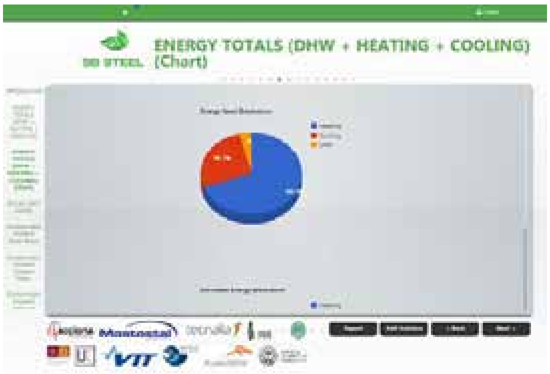


Figure 56. Results: Energy need for DWH production.

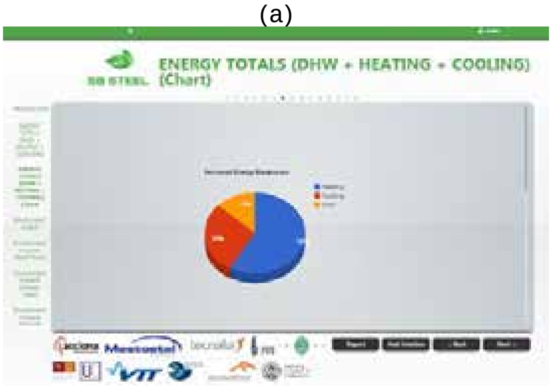
After that, the building total energy need is presented. The breakdown (DWH, heating and cooling) is presented for each month and total energy is presented as (total energy need, delivered energy, renewable energy and primary energy).



(a)



(b)

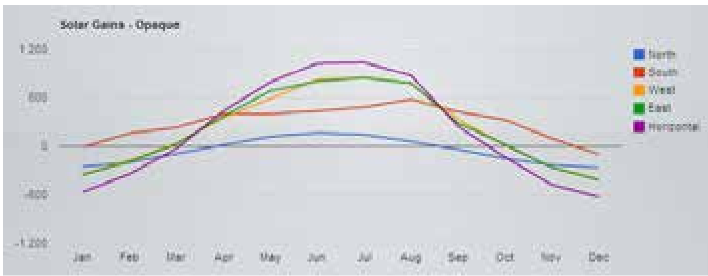


(c)

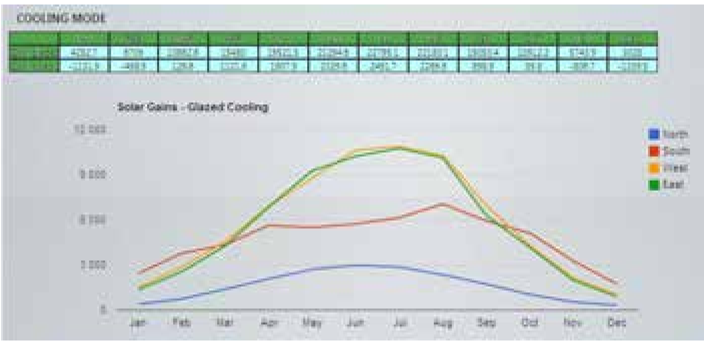
Figure 57. Results: Building energy totals; a) detail in table format; b) energy need breakdown: c) delivered energy breakdown.

Pressing again the “next” button, the software will present the solar gains for both heating and cooling modes. These are presented for both glazing and opaque areas, for each month, in tables. The charts present the annual variation of each orientation (north, south, west and east) for glazing and opaque.

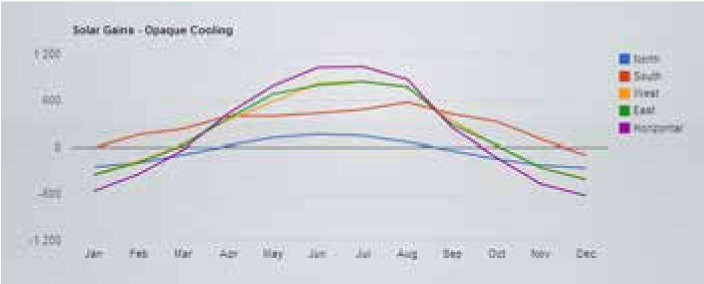
(a)



(b)



(c)

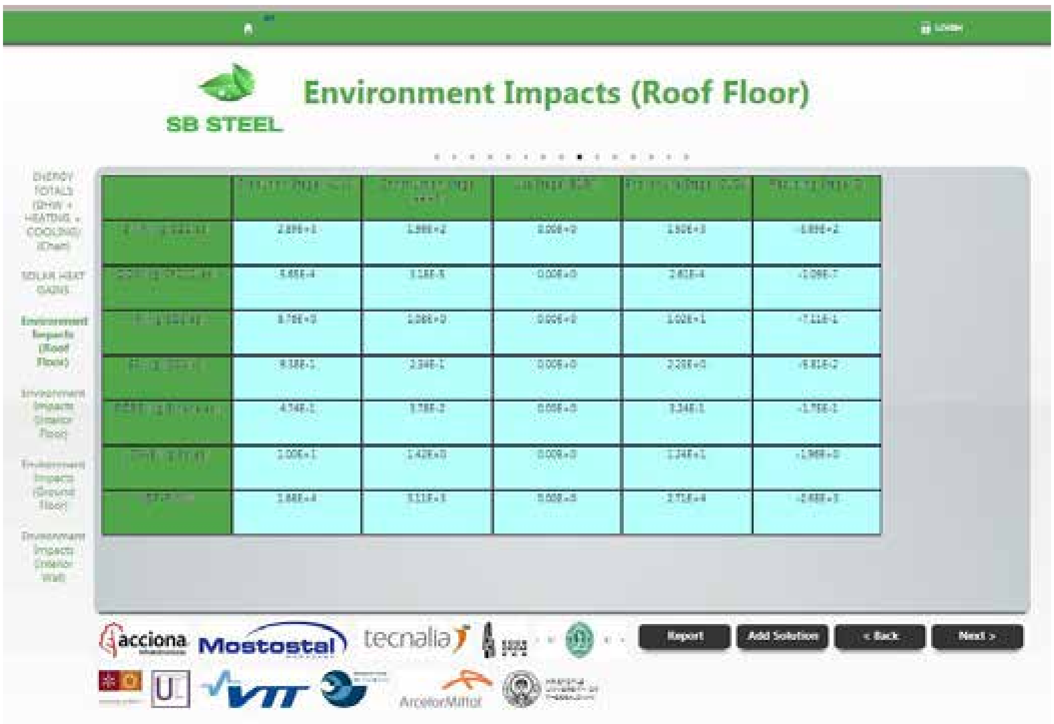


(d)

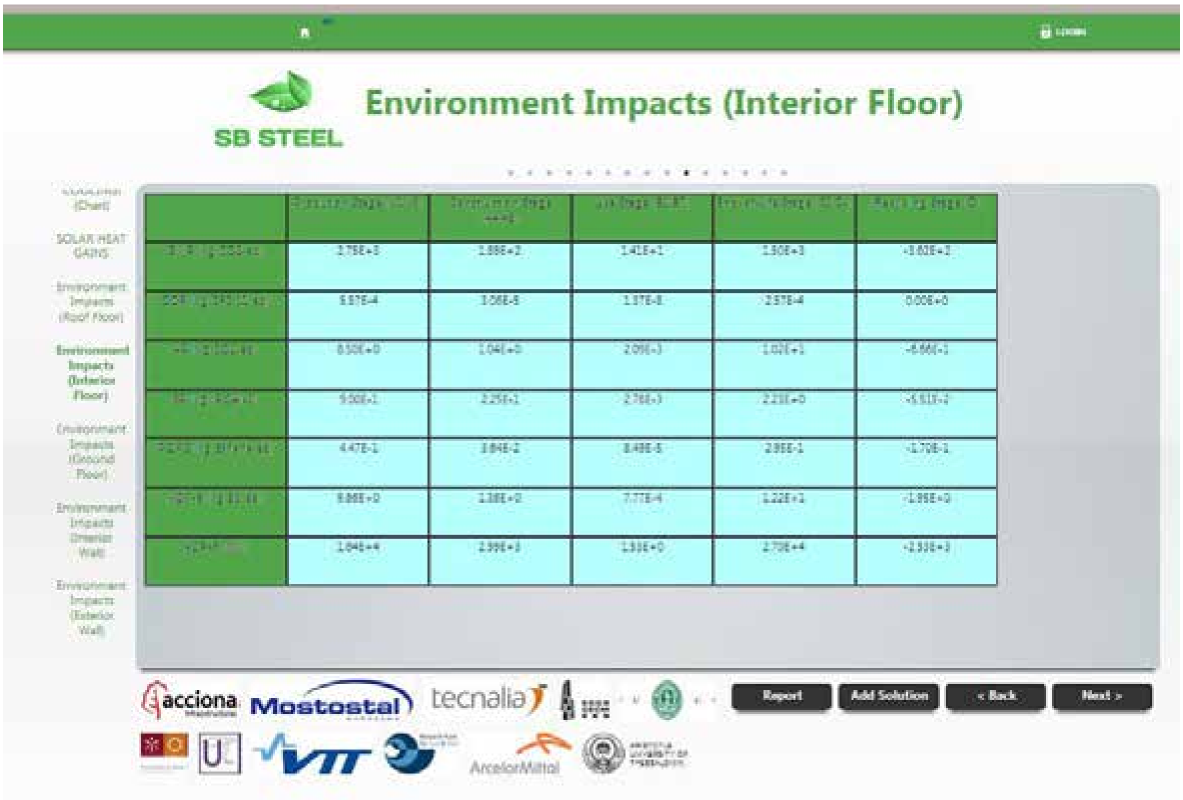
Figure 58. Solar heat gains; a) heating mode – solar gains: glazed; b) heating mode – solar gains: opaque; c) cooling mode – solar gains: glazed cooling. d) cooling mode – solar gains: opaque cooling.

Finally, environmental impacts are presented by macro-component for each life cycle stage (according to the scope of analysis selected) and at the end the whole building impact is shown. The impact categories accounted are:

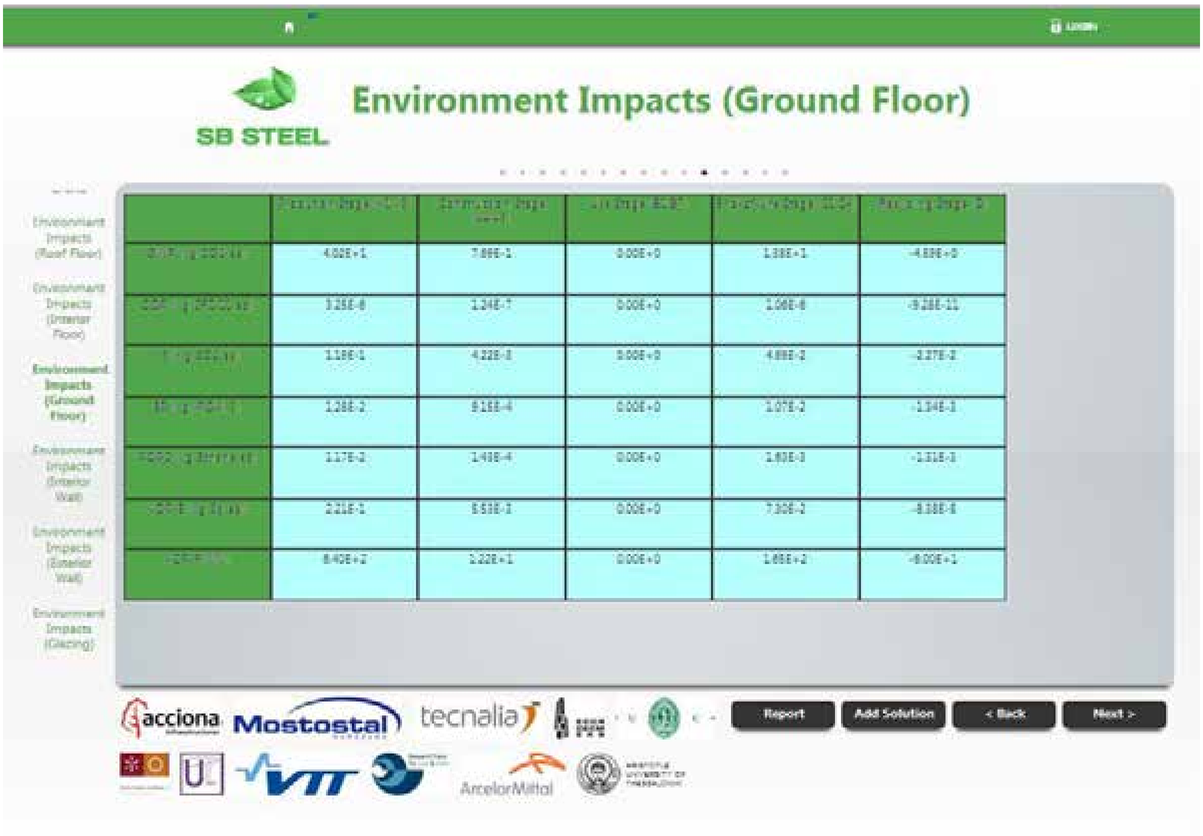
- Global warming potential;
- Ozone depletion potential;
- Acidification potential;
- Eutrophication potential;
- Abiotic depletion potential (fossil fuels and elements);
- Photochemical Ozone Creation Potential.



a)


SB STEEL
Environment Impacts (Interior Floor)
SOLAR HEAT GAINS
Environment Impacts (Roof Floor)
Environment Impacts (Interior Floor)
Environment Impacts (Ground Floor)
Environment Impacts (Interior Wall)
Environment Impacts (Exterior Wall)
Report
Add Solution
< Back
Next >

b)


SB STEEL
Environment Impacts (Ground Floor)
Environment Impacts (Roof Floor)
Environment Impacts (Interior Floor)
Environment Impacts (Ground Floor)
Environment Impacts (Interior Wall)
Environment Impacts (Exterior Wall)
Environment Impacts (Glazing)
Report
Add Solution
< Back
Next >

c)


SB STEEL
Environment Impacts (Interior Wall)
(Roof Floor)
Environment Impacts (Interior Floor)
Environment Impacts (Ground Floor)
Environment Impacts (Interior Wall)
Environment Impacts (Exterior Wall)
Environment Impacts (Glazing)
Environment Impacts (Total)
Report
Add Solution
< Back
Next >
acciona
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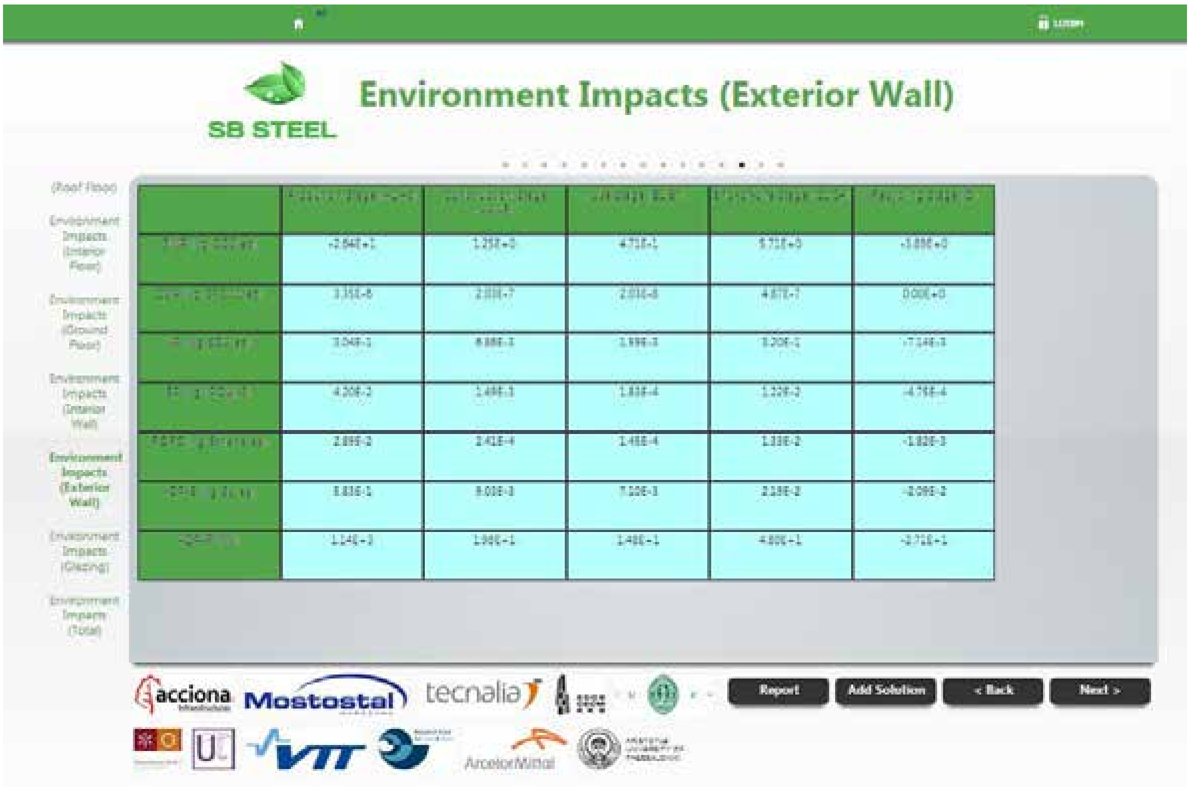
VTT
ArcelorMittal

d)


SB STEEL
Environment Impacts (Exterior Wall)
(Roof Floor)
Environment Impacts (Interior Floor)
Environment Impacts (Ground Floor)
Environment Impacts (Interior Wall)
Environment Impacts (Exterior Wall)
Environment Impacts (Glazing)
Environment Impacts (Total)
Report
Add Solution
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Next >
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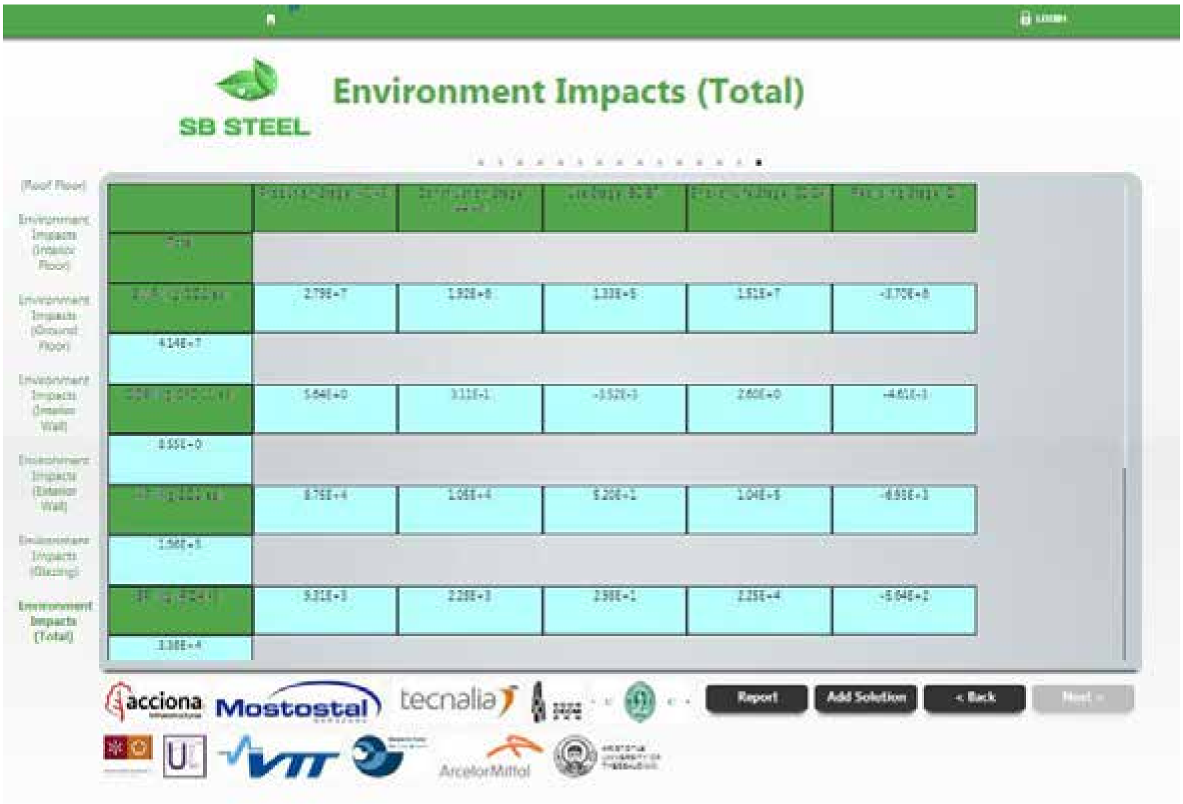
VTT
ArcelorMittal

e)

f)



g)

Figure 59. Environmental impacts (a) roof floor; (b) interior floor; (c) ground floor; (d) interior wall; (e) exterior wall; (f) glazing; (g) total.

2.6.3 Implementation of web page (T6.3)

Task 6.3 refers to the implementation of a web page for public consultation and self-assessment of the proposed methodology. The webpage was implemented for public consultation based on a questionnaire developed by a panel of 3 partners (Coimbra, Timisoara, ArcelorMittal). This panel also assessed the result of the public consultation. The webpage was open for public consultation for 1 year.

2.7 Summary of Workshops

The 1st Workshop

The 1st Workshop **"**Competitiveness of steel buildings in changing markets toward sustainability" was organised in co-operation with the Technical Committee TC14 of ECCS "Sustainability and eco-efficiency of steel building" in accordance with the Technical Annex. The event took place a side-event of the EuroSteel Conference in Budapest on the 1st of September, 2011. The number of participants was 38. The Workshop aimed at answers to the following questions:

i) What approaches are successful in construction markets?
ii) What actions are needed in the future?
iii) What kinds are essential research needs?

The material prepared for the Workshop comprised

- Introductory paper in the Journal for Constructional Steelwork beforehand;
- Poster, including the programme;
- Information at the Conference website (http://www.eurosteel2011.com/)
- Workshop document including slides or papers of presentations at the Conference website and copies distributed in the event;
- Slide sets of presentations made afterwards available to the participants

A summary report was prepared by VTT, and discussed in the 3rd project meeting in Warsaw. The conclusions from the presentations and communication were summarized as follows:

- Updating of database information of various systems needed;
- Improved tools help to show benefits of steel;
- More research for quantification needed;
- Design methods of optimized solutions, technologies for demolition & reuse – good engineering – needed;
- Simulation tools for overall thermal performance of a building needed. Additionally, technologies of indoor control of outdoor peaks – taking into account issue of comfort;
- Markets are not yet asking for an overall sustainability assessment of steel frames;
- Steel industry and constructional steelwork associations have developed similar argumentation both in Europe and North America, mainly based on recyclability of material and structural benefits of light-weight, long spans and prefabrication;
- Decoupling the approaches (EPD's for materials and separately for products and their transportation to sites with average or agreed method);
- Only few holistic systems suitable for pre-design phase of steel-framed buildings;
- Steel is the only truly recyclable material that can be endlessly manufactured to a high quality; this is not fully utilized in argumentation;
- Acceptance of calculation and assessment methods need to be improved through common agreements, visibility and credibility;
- Attention should be paid on argumentation of other framing materials, and changes of regulations in favor of them;
- Methodology to assess sustainability aspects of various technical solutions for retrofitting needs multi-criteria decision-making tools.

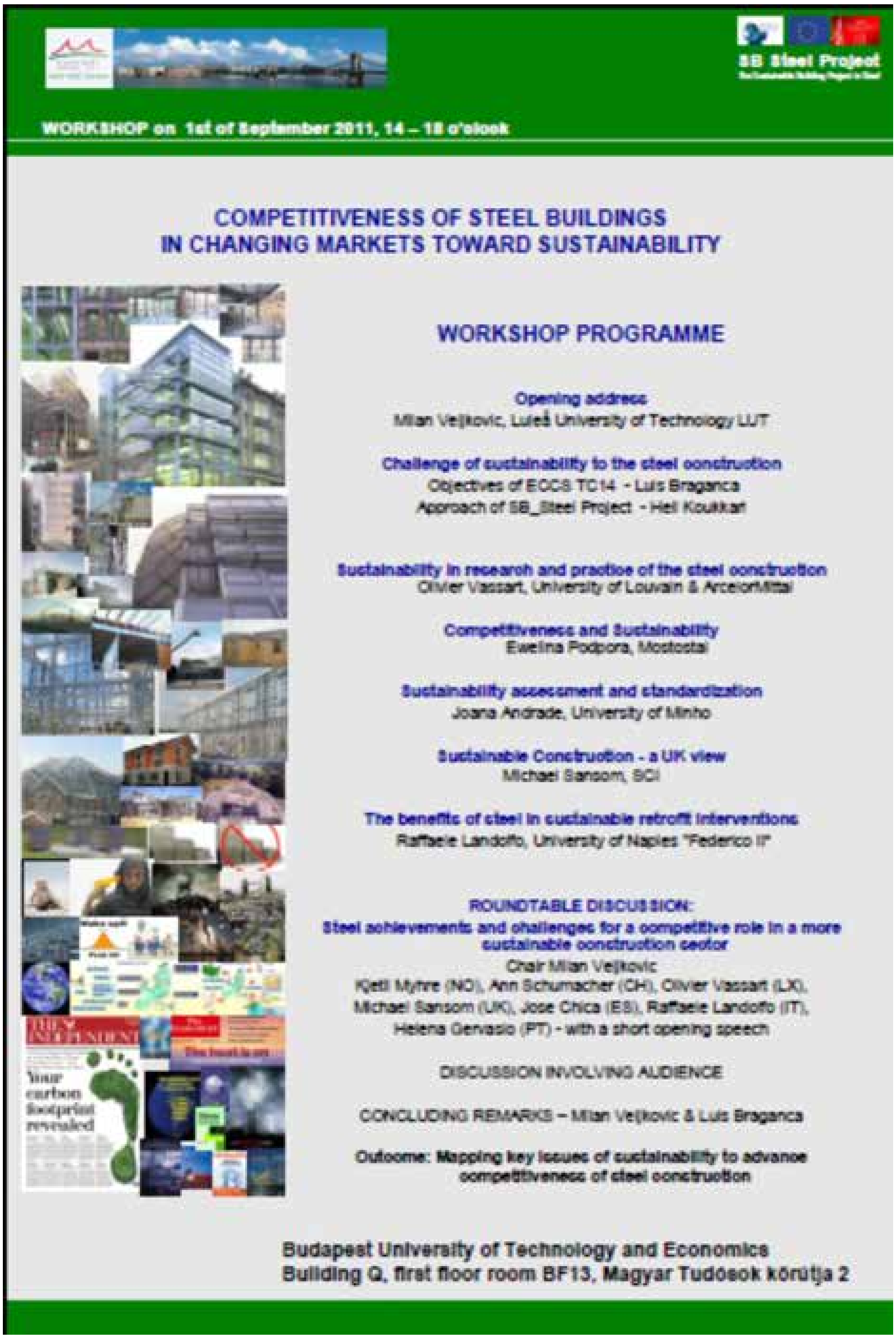


Figure 60. The Poster of the 1st Workshop with the presentations.

Workshop 2

The 2st Workshop *"Concepts and Methods for Steel Intensive Building Projects"* was organised in co-operation with the Technical Committee TC14 of ECCS "Sustainability and eco-efficiency of steel building" and with the WP3 of ESTEP "Construction and Infrastructures Sector". Among speakers, the World Steel Association and Eurofer were represented. The number of participants was 48.

Figure 61. The Poster of the 2nd Workshop.

Workshop 3

The Workshop held in Timisoara, Romania on the 29.01.2013 aimed at a thorough investigation of the outcome of case studies concerning the new approach based on a short list of key indicators and structural macro-components. Eight papers were presented on different types of building projects located in different climatic regions in Europe. In addition, four keynote speeches dealt with indicators of functional service life of structures, comparison between concrete and steel framed low-energy office buildings, sustainable building envelopes and environmental benefits of steel-framed buildings. 40 persons attended.

Workshop 4

The Workshop ('open meeting') held in Guimarães, Portugal on the 25.7.2013 aimed to introduce the new decision-making software developed in the project, and its background and use. It was organised as a side-event of the Conference on Structures and Architecture ICSA 2013 and in co-operation with the Technical Committee TC14 "Sustainability and eco-efficiency of steel building" of ECCS. The session 'Sustainability assessment in early phases of building projects' included project presentations and keynote speeches about LCA approach in steel-framed building design and sustainable design of steel structures. The session 'Web-based support tool for decision-making and examples of application' presented the outcome of the project. 35 persons attended.

3 Conclusions

Two types of indicators were proposed to be considered in the subsequent work packages: core indicators and additional indicators (Table 43). Core indicators were meant for the conceptual stage, whereas additional indicators were regarded more suitable in the latter stages (pre-design). The reason was that the availability of design data was too limited for a larger number of indicators.

Table 43. List of Core Indicators proposed for early design stages.

Environmental Indicators		
Environmental Impact	1	Global warming potential
	2	Depletion potential of the stratospheric ozone layer
	3	Acidification potential of land and water
	4	Eutrophication potential
	5	Formation potential of tropospheric ozone photochemical oxidants
	6	Abiotic Resource Depletion Potential for elements
	7	Abiotic Resource Depletion Potential of fossil fuels
Energy	8	Total Primary Energy Demand
Economic Indicators		
Life Cycle Costs	9	Construction costs
	10	Operation costs
	11	End-of-life costs

The software development and case studies showed that the economic or social indicators are not available to such an extent that they could be immediately included in a tool which aimed at an easy use and reliable outcome. Thus, the list of indicators incorporated to the tool was limited to those for which methods are standardized and generally accepted.

Table 44. Indicators included in the SB_Steel methodology; for both conceptual and preliminary design phases.

Environmental impact categories	Unit	Energy related indicators (kWh/Year)
Global warming potential	Kg CO_2 eq	Heat transfer (heating and cooling season)
Depletion potential of the stratospheric ozone layer	Kg CFC11 eq	Heat Gains (heating and cooling season)
Acidification potential of land and water	Kg SO_2 eq	Energy needs for heating
Eutrophication potential	Kg $(PO_4)^{-3}$ eq	Energy needs for cooling
Formation potential of tropospheric ozone photochemical oxidants	Kg C_2H_4 eq	Energy needs for DHW
Abiotic resource depletion potential for elements	Kg Sb eq	Delivered Energy (for heating, cooling, DWH, total)
Abiotic resource depletion potential for fuels	MJ	Renewable Energy (for heating, cooling, DWH, total)
		Primary energy (for heating, cooling, DWH, total)
		Building's total energy needs

A categorization of renovation project was made in three levels, taking into consideration that renovation projects are in general complex processes where different technologies need to converge into a specific solution. Two main tendencies are clearly identified at this level, structural improvement and functional upgrading, strongly influenced by energy efficient measures but with some other initiatives in the fields of industrialization, sustainability and the use of more recyclable materials with better environmental performance.

Taking as basis indicators addressed for new buildings, the similarities and differences between new and renovated buildings were compared, arising as main difference the necessity to evaluate the improvement obtained by renovating the building, regarding energy consumption and comfort indicators. The decision adopted to consider the same indicators independently of the type of operation to be carried out aligned with the SB_Steel methodology has being demonstrated as useful also for renovation projects.

SB_Steel has proved that under a systemic approach considering macro-components and with the use of Life Cycle tools a more realistic scope of the operation can be obtained, reflecting all hidden impacts additional to just a short term view. Nevertheless, a lack of information related to the construction processes has being clearly identified, emphasizing the necessity of properly quantifying the benefits obtained by offsite solutions for renovation.

As demonstrated, steel solutions are cost effective that thanks to the benefits provided are currently frontline to the Global Challenge that is strongly driving many international initiatives; the efficient renovation of the existing building stock

A pilot version software tool for the assessment of building in early stages of the design process was developed. The implemented methodology addresses the lack of data in early design stages by a macro-component approach that enables to make estimations of the building performance over its life cycle based on simplified shapes and assumptions. Furthermore, the methodology avoids the use of complex tools such as LCA that usually requires some expertise in the field and provides substantial reduction in the time usually needed to perform such analysis. By enabling to make comparative analysis in relation to the most important factors in the lifetime performance of buildings, the tool is useful for designers in the pursuit of a construction solution with lower embodied life cycle impacts and lower energy consumption.

4 Exploitation and impact of the research results

Four workshops were organised during the project in four different countries. The 2nd Workshop was organised together with ESTEP Working Group 3 and ECCS Technical Committee 14. In total, the number of participants was 160.

Figure: Posters of 1st, 2nd and 4th Workshop.

Publications and patents

The document and slides of the first Workshop were published to the participants.
http://www.eurosteel2011.com/down/sb_steel_eccs_workshop.pdf

The Proceedings of the Workshop 2 were freely distributed in the event and among partners; partners of the project have also the pdf version available at VTT's Extranet.

Koukkari, H., Braganca, L. & Boudjabeur, S. (Eds.) 2012. Concepts and methods for steel intensive building projects. ECCS Publications No 130. ECCS – European Convention for Constructional Steelwork, Mem Martins, Portugal. ISBN 978-92-0147-106-5 242 p.

Proceedings of the 3rd Workshop on sustainable building projects in steel – case studies for a new design approach: January 29, 2013, Timisoara, Romania.

edited by V. Ungureanu, A. Ciutina, H. Koukkari. – Timişoara: Orizonturi Universitare, 2013
ISBN 978-973-638-526-1

Total number of pages: 318

The software for the assessment of a building project in early stages is a novel type of platform in the steel construction sector. It addresses the lack of data through a macro-component approach that enables to make accurate estimations of the building performance over its life cycle based on simplified shapes and assumptions. By enabling to make comparative analysis in relation to the most important factors in the lifetime performance of buildings, the tool is useful for designers in the pursuit of a construction solution with lower embodied life cycle impacts and lower energy consumption.

SB_Steel has proved that under a systemic approach considering macro-components and with the use of Life Cycle tools a more realistic scope of the operation can be obtained, reflecting all hidden impacts additional to just a short term view. Nevertheless, a lack of information related to the construction processes has being clearly identified, emphasizing the necessity of properly quantifying the benefits obtained by offsite solutions for renovation.

The software was coded by one partner and its sub-contractor and the partner is the owner of the IPR. The use of the pilot software is however free and it is made public through ECCS's website. ECCS's Technical Committee TC14 will promote use and development of software in future, and the issue will be permanently in its agenda.

The project 'Large Valorisation on Sustainability of Steel Structures' has been launched with 19 partners covering 17 European countries that includes further dissemination of the SB_Steel project, too. Its technical objective is to disseminate the knowledge acquired in the recent years about the environmental impact assessment of steel and composite buildings.

During the last decade, a lot of research projects have been funded to develop methodologies, systems and products aiming at improving the thermal efficiency as well as the global environmental footprint of steel buildings. The new standard EN15804 intended for environmental calculation of buildings takes now into account the fact that steel is a recyclable material (Module D). Within this project, documents such as leaflet and design guides and software … will be created and disseminated amongst Europe by the organisation of workshops.

List of figures

List of tables

List of acronyms and abbreviations

ASTM – ASTM International Standards Worldwide (formerly known as American Society for Testing and Materials)
BREEAM – The Building Research Establishment's Environmental Assessment Method
CEN – European Committee for Standardization
CIB – International Council for Research and Innovation in Building and Construction (formerly known as Conseil International du Bâtiment)
CPR – Construction Product Regulation of EU
ECCS – European Convention for Constructional Steelwork
ECCS TC 14 – ECCS Technical Committee on Sustainability and Eco-Efficiency of Steel Building
EOL – End-of-Life
EPBD – Directive on the energy performance of buildings
ESTEP – European Steel Technology Platform
Eurofer – European Confederation of Iron and Steel Industries
GWP – Global Warming Potential
iiSBE – international initiative for Sustainable Built Environment
ISO – International Standardization Organization
LCA – Life Cycle Assessment
LCCA – Life-cycle cost analysis
LCEA – Life Cycle Environmental Assessment
LCIA – Life-cycle-inventory assessments
MCDM – Multi-criteria decision-making
PEC – Primary Energy Consumption
RFCS – Research Fund for Coal and Steel
RR – Recycling rate
SBTool – Sustainability assessment tool developed by iiSBE
SD – Sustainable development
SRA – Strategic Research Agenda
UNEP – United Nations Environment Programme
WBCSD – World Business Council for Sustainable Development
WSA – World Steel Association (formerly known as International Iron and Steel Institute IISI)

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The SB_Steel project delivered concepts and methods for sustainable building projects and a decision-making platform to support selection of steel-intensive solutions in the early design phases. The decision-making platform is made available to various operators of the steel construction sector.

The Work Package 1 gathered and preliminarily studied research data from a great number of areas which are related to the objectives. WP2 developed design approaches and assessment methods for a new building project, and WP3 for renovation. The software tool was developed in WP4, and case-studies were performed in WP5. WP 6 was focused to produce design examples using the software. Communication about project results was done in four Workshops that were organised also together with the Technical Committee TC14 of ECCS and the Working Group 3 of the European Steel Technology Platform ESTEP. The Proceedings of 2nd and 3rd Workshops were published as hardcover books.

The software for the assessment of a building project in early stages is a novel type of platform in the steel construction sector. It addresses the lack of data through a macro-component approach that enables to make accurate estimations of the building performance over its life cycle based on simplified shapes and assumptions. By enabling to make comparative analysis in relation to the most important factors in the lifetime performance of buildings, the tool is useful for designers in the pursuit of a construction solution with lower embodied life cycle impacts and lower energy consumption.

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