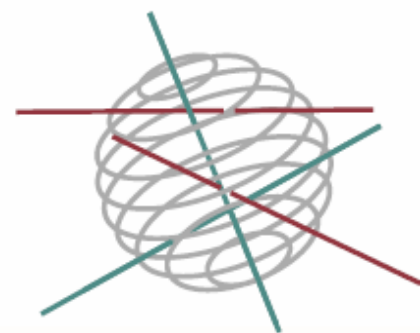


SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT



**SUSTAINABILITY, FINANCIAL AND QUALITY EVALUATION
OF DWELLING TYPES
“SUFIQUAD”
SD/TA/12A**

K. ALLACKER, F. DE TROYER, K. PUTZEYS, A. JANSSENS,
C. SPIERINCKX, A. VERCALSTEREN



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TRANSPORT AND MOBILITY 

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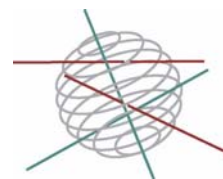
CLIMATE 

BIODIVERSITY   

ATMOSPHERE AND TERRESTRIAL AND MARINE ECOSYSTEMS   

TRANSVERSAL ACTIONS 

SCIENCE FOR A SUSTAINABLE DEVELOPMENT (SSD)



Transversal Actions



FINAL REPORT PHASE 1

**SUSTAINABILITY, FINANCIAL AND QUALITY EVALUATION
OF DWELLING TYPES
“SUFQUAD”
SD/TA/12A**



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ACRONYMS, ABBREVIATIONS

CBA	Cost Benefit Analysis
EAP	Energy Advice Procedure
EOL	End-of-life
EPB	Energy Performance for Buildings
EPC	Energy Performance Certificate
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
MCA	Multi-Criteria Analysis
OC	Guiding Committee

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1. INTRODUCTION

1.1. CONTEXT

Current approaches aiming at a sustainable development of the building sector are focusing on the different actors separately (building materials, energy use), while abstracting the complex interrelations. This allows for a detailed analysis but misses a global objective by losing the overall picture. Worth mentioning in this perspective are recent projects as ‘the energy performance standard’ and the ‘Best Available Techniques (BAT)’ – studies at sector level.

Life Cycle Assessment (LCA) in the building sector is most often carried out at the level of materials and components, and not at the level of the building. This is summarized in the document: ‘life-cycle assessment in building and construction: a state-of-the-art report’ (SETAC Press, North Carolina, USA, Society of Environmental Toxicology and Chemistry (SETAC), 2003, pp. 86). Since the design of a building (typology, lay-out, dimensions, orientation, location, etc.) determines the overall environmental impact, a building cannot be equated to the sum of its constituting components.

The originality of the proposed ‘**integrated**’ research lies in the fact that the analysis will be carried out at the building level, considering all interrelated influences and stakeholders. Moreover all aspects of interest will be considered by integrating classic financial evaluation techniques (investment cost evaluation, cost-in-use simulations,...), traditional environmental evaluation methods (LCA, environmental external costs,...) and a quality evaluation (based on an existing method: “Method for the evaluation of the quality of dwellings in the design phase, Ministry of the Flemish Government, Belgium, 1991”). Moreover the environmental impacts will be expressed in monetary values enabling an integrated assessment including financial costs.

1.2. OBJECTIVES

The project departs from the need for an **integrated** approach aiming at a **typology-specific** analysis concerning the reduction of the environmental impact of the building and housing sector, taking into account the building performance (functional, spatial and environmental performance) and financial consequences.

The aim is therefore to develop and apply a methodology to evaluate both the initial and future costs (financial and environmental) and benefits (qualities) of different housing types. Investigating a number of technical, spatial and user behaviour parameters will lead to identifiable recommendations for the stakeholders and form a basis for policy making.

More particularly, **the goal** is to clarify possible conflicts between decisions based on financial investment costs, total financial costs, environmental investment costs, total environmental costs, the sum of both and finally these costs in relation to the performance assessment of the dwellings.

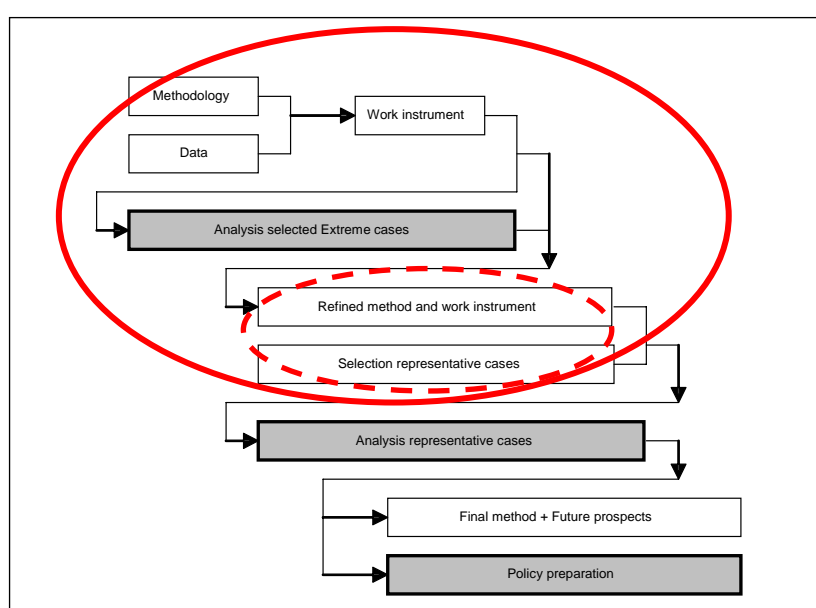
The expected outcome of the research is to yield a background document for policy making which considers policy measures in relation to a more sustainable building and housing sector.

2. SCIENTIFIC APPROACH AND PHASING OF THE PROJECT

In the figure below, the methodological approach is shown schematically. During the first phase, the methodology and work instrument have been developed, the necessary data were gathered and the extreme dwelling types have been selected and analysed with the developed work instrument.

Finally, representative dwelling types have been selected to be analysed with the same approach in the second phase of this project.

In the figure below the red circle indicates which part of the methodology has been executed during the first phase of the project. The dotted red circle indicates the part which was initiated during the first phase, and which will be further elaborated during the first semester of the second phase.



Moreover, a first preparatory policy document has been elaborated based on the approach and results of the analysis. However, this should be further elaborated during the second phase of the project based on the analysis of the representative dwelling types.

In the following paragraphs, a more detailed description of the scientific approach followed in the consecutive phases is elaborated.

First six months

Summary: The development of the methodology consists of different aspects, namely:

- Evaluation of international tools and models
- LCA, LCC and quality evaluation
- Monetary valuation of environmental impacts

For each of these aspects methodological decisions have been taken based on a critical literature review and a proposal for ‘integrated approach’ has been made. A description of the international tools and models, the methodological decisions within SuFiQuaD for each of the aspects and the proposal for integrated approach have been reported in four intermediate notes (see ‘intermediary results’ further on). This has been presented to the OC in June 2007 (14/06/2007).

Moreover, a workshop was organized by the three partners at the European Roundtable on Sustainable Consumption and Production (ERSCP07) in Basel, Switzerland at the end of June 2007 (21/06/2007). Following a presentation of the proposed ‘integrated’ approach, discussions

were started on five topics related to questions concerning the proposed method. After a brainstorming session, the most important ideas of each topic were selected and discussed. The results of the workshop were summarised on a poster and presented to the public of the ERSCP conference.

Within the quality assessment of the dwellings, different qualities are weighted in order to obtain a single score. The weighting factors within the existing method used were determined by a group of experts but date from 1990. Therefore it has been decided (on the meeting with the OC in June 2007) that these should be re-evaluated. The weighting factors are determined based on pair-wise comparisons of the qualities considered. To limit the number of pair-wise comparisons, the qualities have been structured hierarchically. The aim was to revise the weighting factors by an inquiry sent to the architects in Belgium (Flemish and French version). This inquiry was developed by the K.U.Leuven and sent to the ‘Orde van Architecten’ (Jos Leysen), however it was never sent to the architects because the ‘Orde van Architecten’ feared that more requests for surveys would follow this precedent. Since once all external costs are internalised, the quality evaluation can be done by each decision maker, only the results of a pre-test of the enquiry will be used. All parameters however are adaptable. The most important aim is to prove how, on top of financial and environmental costs, quality is influencing decisions.

K.U.Leuven started with the translation of the methodology into a work instrument both for the LCA and quality assessment, while VITO and CSTC started with the gathering of the LCA and LCC data. A literature study revealed that specific data for the Belgian context concerning transportation of the building materials and EOL treatment was lacking.

Second half of the first year

Summary: *the developed methodology has been further translated by the K.U.Leuven into a first version of a work instrument. Moreover, during this phase, the extreme dwelling types have been selected and the necessary data were gathered. The first version of work instrument was presented to the OC in December 2007 and delivered in January 2008. Moreover a description of the extreme dwelling types and the gathering of the data have been reported in three intermediate notes. This has also been presented to the OC in December 2007. Each of these activities is described in more detail below.*

The proposed methodology has been further translated into an excel tool by the K.U.Leuven. On a regular basis the tool is presented to and discussed with the other partners to ensure that the data the other partners are gathering can easily be integrated in the tool. The tool is structured following the BB/SfB codes and enables to compare different technical solutions for each element fairly easy. For each analysed dwelling the different elements are then combined by calculating the ratio of each element.

For the quality evaluation, K.U.Leuven developed a second spreadsheet. The spreadsheet is divided in two files: an input and analysis file. The first is used by the different partners to input the data of the analysed dwellings. The second file is used by the K.U.Leuven to assess the different files. This has been decided to ensure that future changes in the methodology (weighting factors, score functions, included aspects, ...) are applied to all dwellings by adapting one file (the analysis file). It will therefore not be required to revise the input if the methodology would be adapted. These spreadsheets were also presented to the OC in December 2007 and described in an intermediate note.

VITO was responsible for the selection of extreme dwelling types. This has been done based on discussions with the three partners. It was decided to analyse four extreme types: a freestanding and a terraced house, an apartment (multi-family dwelling) (all newly built) and a renovated terraced house. This selection was made to enable to address most of the expected methodological problems, e.g. shared walls in the case of a terraced house, shared space in the case of apartments and refurbishment measures in the case of the renovated terraced house. For

each dwelling the plans and bills of quantity have been gathered/developed by VITO and K.U.Leuven.

After the selection of the extreme dwelling types, different (extreme) alternatives for the constituting building elements were defined wherefore K.U.Leuven and CSTC prepared detailed descriptions, while VITO made a selection of technical installations for the different dwellings.

The necessary data for the analysis of both the extreme and representative dwelling types have further been gathered by the three partners. VITO has gathered the LCA data, while CSTC and K.U.Leuven gathered LCC data. Most of the data are taken from an existing and publicly available database. For the LCA data, the Ecoinvent database was used, which consists of European data. When required and when data were available, the original Ecoinvent data were adapted to the Belgian context. For the LCC the ASPEN database was used. This database contains specific data for the Belgian context, distinguishing between new buildings and renovations. Only the data for new buildings were gathered so far.

LCA data were gathered per vehicle type by VITO and reported per ton-km transported material or per person-km for the passenger car. However data were still needed regarding the transportation distances and the type of vehicles used for each material. A literature study, carried out by CSTC, revealed that these data were lacking for the Belgian context. Therefore CSTC set up a survey to gather the necessary data. A questionnaire was sent to contractors, producers and dealers of construction products, and container and sorting companies asking about their specific data concerning transport of products to the building site, transport of construction and demolition waste, and EOL treatment of construction and demolition waste.

The data about the initial costs were gathered by the K.U.Leuven. This was described in an intermediate note (January 2008). CSTC gathered the data about cleaning, maintenance and replacements. This seemed not to be an easy task, since a large difference is noticed within the different sources. This was also described in an intermediate note (January 2008).

First half of the second year

Summary: *the processing of the inventoried LCI data was done at the element level and the work instrument was further developed. Moreover CSTC processed the data of the survey concerning transportation and EOL treatment. Also the operational costs have been further elaborated by CSTC during this period. VITO made an analysis of the available tools for the calculation of the heating demand of dwellings during use phase and the most appropriate method for the application within the SuFiQuaD project was selected. This method is mainly based on the EPW-method that is compulsory in the Flemish region, but with required adaptation for the aim of this project: dimension based on reference lines (no internal nor external dimensions), no “conventional” hypothesis regarding cooling loads,... Two of the four extreme dwelling types have been analysed in this phase. Moreover, CSTC made an overview of the current policy measures and other initiatives concerning sustainable building in the Belgian context. The latter was not foreseen in the original work plan but was done on request of BELSPO. Finally, the three partners together made a first proposal for policy based on the SuFiQuaD approach and first results of the application on extreme types. The further elaboration and analysis of the extreme dwelling types was further elaborated in an intermediate note (July 2008). Moreover the current policy and proposed policy based on SuFiQuaD were summarized in two intermediate notes (July 2008). Each of these activities is described in more detail below.*

The LCI data from the Ecoinvent database are used to calculate the integral environmental impacts per kg or m³ building material. For each material/process used, the integral environmental impact in EURO / unit (kg, m³, MJ,...) had to be calculated with the chosen approach (elaborated in the note ‘note on monetary valuation of environmental impacts’ (cfr. ‘intermediary results’ further on)). The K.U.Leuven therefore elaborated a spreadsheet based on the LCA data gathered and calculated by VITO. The results of this spreadsheet are the integral environmental impacts expressed in euro/kg material, euro/MJ energy, euro/ton-km transport and

euro/person-km transport.

While for the financial cost, data were available per unit of element, this was not the case for the LCA data. Therefore, the amount of material/process per unit element needed to be determined for each technical solutions of each element, expressed in kg or MJ/ unit of element. A precise quantification of the amounts for the different element alternatives was elaborated by CSTC and K.U.Leuven based on the earlier mentioned descriptions. Moreover, K.U.Leuven developed a spreadsheet to easily translate the monetary values per kg material to monetary values per unit of “work section” and “building element” based on the above input. This process was reported in an intermediate note (July 2008) and presented to the OC in June 2008.

Based on the results of the questionnaires sent by CSTC concerning transportation and EOL treatment of building materials, different building material categories were defined. For each of these categories a transportation scenario was elaborated based on the results of the questionnaires. The same was done for the transport of construction and demolition waste, where a transportation scenario was developed for different waste types. Furthermore, for each of the different waste types, an EOL treatment scenario was developed. Both the processing of these data and the developed spreadsheet are described and illustrated in an intermediate note (July 2008). Moreover this was presented to the OC in June 2008.

The above defined transportation and EOL scenarios for the defined building material categories were combined with the inventoried data of VITO in a spreadsheet developed by K.U.Leuven. The results of the spreadsheet concern the environmental impact per unit building element for the transportation from the production site to the construction site, for the transportation of the construction site to the EOL treatment plant and for the EOL treatment process itself. Again this was presented to the OC in June 2008 and elaborated in an intermediate note (July 2008).

CSTC made a detailed literature study on the data required for the calculation of the operational costs. These concern the cleaning costs, the maintenance costs and the replacement costs. Several data were needed: frequency, activity, financial cost and life span of the different work sections and elements. VITO searched for the corresponding LCI data of the different cleaning products and activities (for example vacuum cleaning) and calculated the integral environmental cost related to these cleaning products and activities (LCA). This was elaborated in an intermediate note (July 2008). Finally, these data were integrated in the LCA/LCC tool by K.U.Leuven.

The calculated data per unit of building element collected in the spreadsheets described above (production, transportation, EOL transportation, demolition and EOL treatment) were then entered in the LCA tool (worksheet: database) together with the financial cost data (initial material and labour cost (incl. transportation to the construction site, operation costs). The financial costs concerning demolition and EOL treatment still need to be gathered.

For the calculation of the annual energy consumption for heating and hot tap water during the use phase of the dwellings, VITO used three different Belgian calculation procedures, and compared the results of these for the four selected extreme dwelling types. The three applied calculation tools are EPB (Energy Performance for Buildings), EAP (Energy Advice Procedure) and EPC (Energy Performance Certificate). From this comparative analysis, it was decided that EPB was the most appropriate within the context of SuFiQuaD. However, some adaptations were suggested, which will be integrated in a translated version of the EPB programme in excel. The results of the comparative analysis are reported in an intermediate note (July 2008).

For a summarized description of the results of the implementation of the first two extreme dwelling types, we refer to the next section (results).

CSTC made an overview of the current policy and incentives concerning sustainable building in the Belgian context. With regard to Belgian policy initiatives, a distinction was made between the initiatives at the Federal level, in the Brussels-Capital Region, the Walloon Region and the

Flemish Region. For each of these political levels, an overview was made of the most important policy documents, of the governmental institutions dealing with (aspects of) sustainable construction and of existing financial incentives to stimulate more sustainable construction (or at least some aspects of it). This was partly presented on the OC in June 2008 and described in an additional intermediate note (July 2008).

The three partners together made a first proposal (July 2008) for policy regarding sustainable building based on the SuFiQuaD approach and the first results of the simulations. However this will be further elaborated during phase two based on the analysis of the representative dwelling types. This was not foreseen in the original work plan but was asked by BELSPO at the start of the project.

Second half of the second year

Summary: *two additional extreme dwelling types were analysed, i.e. the apartment and the renovated terraced house. The three partners together elaborated a methodology for the analysis of the specific aspects of multi-family dwellings and renovation. While K.U.Leuven carried out the LCA/LCC study, CSTC made the quality evaluation. VITO investigated further the transportation files within Ecoinvent and recalculated the EOL environmental cost based on findings of the K.U.Leuven. During this second half year, CSTC and VITO analysed the import of building materials more in detail. Furthermore, the representative dwelling types were selected based on an extended literature study by the three partners. Moreover, representative building elements were defined by CSTC and representative technical installations by VITO. These different aspects were presented to the OC in December 2008 and summarized in four notes (December 2008). Each of these activities is described in more detail below.*

For the apartment, a methodology was worked out to assign part of the cost of shared space and shared elements in the apartment building to the analysed apartment. Moreover, for the renovated terraced house, a method was developed to assign part of the initial cost of the original dwelling to the previous dwelling owner and to the second owner. Both approaches were described in detail in the final note on extreme cases (December 2008).

K.U.Leuven made the LCA and LCC analysis of the apartment, based on the earlier collected LCA and LCC data of the different element as described before. However, for the apartment building, pile foundations were used, which was a new element and had to be added to the LCA/LCC file. Moreover, the energy calculations had to be extended since VITO did not execute the calculations for all variants during the first half of the second year. The quality evaluation of the apartment was executed by CSTC. Both the LCA/LCC and quality results, together with the optimisation, were described in detail in the final note on extreme cases (December 2008).

During the analysis of the apartment, K.U.Leuven investigated some elements in detail. This resulted in the observation that the environmental benefit of some building elements was larger than the environmental burden for the production of that element. This contradiction had to be solved and was investigated in more detail. VITO resolved this contradiction by defining specific EOL processes instead of using the generic EOL process files as available within Ecoinvent. This was described in detail in the final note on extreme cases (December 2008).

For the renovated terraced house, a methodology was elaborated by the three partners to attribute a correct part of the initial cost of the original dwelling to the previous and second dwelling phase. The «accountancy» approach was used in order to enable comparison of renovation and new construction. A more detailed description of this approach was given in the «final note on extreme cases» (December 2008).

The LCA/LCC analysis of the renovated terraced house was done by the K.U.Leuven. The financial cost data for this dwelling were collected, since prices for renovation differ from new buildings. In 2008 ASPEN published a new version of their database. This latest version was used for the analysis of the renovated dwelling. However, for the analysis of the representative types in

the second phase of the project, the financial cost data for new buildings still needs to be updated to this newest version of ASPEN. For the energy consumption during use phase, K.U.Leuven had to extend the calculations that VITO carried out during the first half of the second year, since not all calculations for all variants were executed. CSTC made the quality evaluation of the different alternatives of the renovated terraced house. Both the LCA/LCC and quality, together with the optimisation results are described in detail in the « final note on extreme cases ». (December 2008).

During the last six months of the first phase, the study focused further on the import of building materials. Both the import of wood and blue stone to Belgium and the import data within the Ecoinvent database were investigated in detail. The results of this analysis will be used for the analysis of the representative dwelling types in the second phase of the project.

Furthermore, preparatory work for the second phase of the project was done by analysing the current dwelling stock and selecting the representative dwelling types. In a first step, a methodology for selecting representative dwelling types was identified based on an extensive literature study. Secondly, the statistical spread of dwelling types in Belgium was determined based on an analysis of national and regional statistics. Both dwelling type and construction period were taken into account here. Finally, a number of dwelling types that are considered as representative for the whole Belgian dwelling stock were selected and classified according to type and construction period. A more detailed elaboration of this work is given in the “Note on selection of representative dwelling types” (December 2008).

Moreover, representative building elements were defined based on an extensive literature study. This resulted in a detailed overview of common technical solutions for the main building elements within a dwelling, i.e. external walls, internal walls, roofs, floors, windows and doors, staircases, railings and balustrades and the electricity grid, as well as for rainwater drainage and recovery and drives and terraces. These technical solutions represent the basis for further definition and optimisation of representative building elements and finally also entire dwellings during the second phase of the project. The detailed list of technical solutions for building elements is given in the “Note on selection of representative element types” (December 2008).

Finally, representative technical installations were selected. The definition of technical installations for the different dwelling types is mainly in accordance with the Belgian EPC (EnergiePrestatieCertificaat) methodology. This definition of technical systems results in a set of parameters for each of these installation. The actual selection of the different representative technical installations is based on known statistical information (NIS, PODOSEREC, EAP database), experience of VITO with these systems, the history of installations and experts in the sector. More detailed information can be found in the “Note on technical solutions” (December 2008).

3. RESULTS

The results of the first phase of the project are summarized in the paragraphs below. At first, the results regarding the elaboration of the methodology are described, followed by a description of the results regarding the implementation of the methodology to four extreme dwelling types.

3.1. RESULTS REGARDING THE ELABORATION OF METHODOLOGY

The intermediate results of the project have been periodically described in the following intermediate notes:

- K.U.Leuven: Note on optimising economic, environmental and quality aspects (130 pages) (August 2007).
- VITO: Note on monetary valuation of environmental impacts (48 pages) (update January 2008).
- VITO: Note on LCA data in view of the project (36 pages) (update January 2008).
- CSTC: Note on European research and standardisation (126 pages) (update August 2007).
- K.U.Leuven: Basic version of work instrument (spreadsheet) (January 2008).
- K.U.Leuven: Note on quality evaluation (35 pages) (January 2008).
- VITO: Note on selection of extreme types (75 pages) (January 2008).
- CSTC: Note on LCC (15 pages) (January 2008).
- CSTC: Interim note on Extreme Cases (68 pages) (July 2008).
- CSTC: Note on Belgian Policy (40 pages) (June 2008).
- K.U.Leuven, CSTC, VITO: Interim note for policy preparation (14 pages) (June 2008).
- CSTC/K.U.Leuven: Note on selection of representative dwelling types (41 pages) (December 2008).
- CSTC: Note on selection of representative element types (32 pages) (December 2008).
- VITO: Note on technical solutions (21 pages) (December 2008).

Within the first note ‘**note on optimising economic, environmental and quality aspects**’, an overview is given of the different aspects within the aimed integrated approach. These are structured in five chapters:

- LCA – general methodology
- LCA at the building level
- Life Cycle Costing
- Functional unit – the element method
- Quality evaluation of dwelling types
- Optimising economic, environmental and quality aspects

The first two chapters describe the evaluation of the environmental impact of dwellings. While the first chapter elaborates on LCA in general, the second chapter describes the problems and approach when trying to carry out a LCA at the building level. The different steps of a LCA are described and the application of these in the context of SuFiQuaD is elaborated. The third chapter describes the determination of the financial costs over the whole life cycle of the dwelling. A LCC is proposed including both the investment costs as the operational costs in the evaluation. The sum of the present values is then calculated to obtain the life cycle costs of the dwellings. In the fourth chapter attention is given to the choice of the functional unit within this research. Both the environmental impact and financial cost are calculated per square meter of total floor area, per year. To be able to structure the data inventory in a systematic way, the element method for cost control is used and extended with operational costs and environmental impacts. The fifth chapter focuses on the quality evaluation of the dwellings. A single score is obtained by carrying out a multi-criteria analysis (MCA). An existing method is adapted to the objectives of this research. Both the original method and the necessary adaptations are elaborated. In the final chapter a technique

is chosen to optimise the three aspects, namely financial cost, environmental impact and quality. Different optimisation techniques are described, such as cost-benefit analysis, multi-criteria analysis, the ecological footprint and the spider model. The cost-benefit analysis is chosen as optimisation technique within the context of SuFiQuaD. The Pareto front is proposed to determine which alternatives have the highest quality increase for the lowest extra life cycle cost spent in comparison with the reference dwelling. Budget restrictions are used to take into account the limited budget.

Within the ‘**note on monetary valuation of environmental impacts**’, the important aspect of “monetising environmental impacts” is discussed. In this document an overview is given of existing methods. The most appropriate existing method has been selected based on the following criteria:

- accuracy and scientific justification;
- completeness and consistency.

The damage function approach seemed the most appropriate; however, when trying to implement it, it became clear that no existing study covered all major impact categories. Therefore it was decided to use a ‘hybrid’ approach. For the emissions covered by ExternE, these values were used. For the impacts and emissions not included in ExternE, Eco-Indicator 99 was used and translated into monetary terms. For the latter translation, different sources were used. In the update of January 2008 the assessment of the emission of PM10 has been further elaborated and the some suggestions were made for sensitivity analysis.

Within the ‘**note on LCA data in view of the project**’, an overview is given of the different LCI / LCA databases to be used within the SuFiQuaD project. Two groups of data are considered: generic data and data for the building sector. The generic data comprise as well energy as transportation. For these, priority will be given to the Ecoinvent database. If data are lacking, the ETH and BUWAL database will be consulted. Only if these three databases do not contain information on a specific process of material, the IDEMAT and IVAM databases will be used. Besides these data, we need to gather data specific for the building sector, such as for example data about the production of the building materials, the construction and demolition processes. For these data it was decided that again priority would be given to Ecoinvent. If data are lacking, other databases will be used, such as IVAM, Dutch concrete database, BUWAL and ETH. Finally some remarks are made about combining different databases. The update of January 2008 concerns the choice of technical installations, the selection of a representative electricity mix for all life cycle stages of the building, the well-founded choice to not include domestic water consumption, a well-founded choice to include the impacts related to infrastructure during the whole life cycle, and a further elaboration of the methodological approach concerning the EOL (end-of-life) phase of the dwellings.

Within the “**note on European research and standardisation**”, an overview is given of the state-of-the-art concerning LCA, LCC, quality evaluation and the policy framework in several European countries. For each of the different themes, the most interesting countries are looked at in detail. At first, different approaches on LCA, which are concentrating either on the building level or on the building product level, in different European countries (i.e. The Netherlands, France, United Kingdom, Germany, Denmark, Norway, Finland and Sweden) are described in detail. Secondly, both international and European developments on LCC and the implementation of LCC in a number of European countries (i.e. UK, Ireland, The Netherlands, France, Germany, Finland, Sweden, Norway and Spain) are described. Furthermore, different quality evaluation methods that are used in different European countries (i.e. UK, The Netherlands, France and Switzerland) are evaluated. For the Belgian context, two methods are mentioned, of which one, i.e. the method that was developed as early as 1990 for the Flemish Government, will be used as a starting point for the quality evaluation within the SuFiQuaD project. Finally, the policy framework within the European context is described. Here, both the European policy in general and country specific

involved in the policy development in the different countries. Moreover, the visions, strategies, implementation plans and policy documents are listed for the considered countries.

The **basic version of the work instrument** is a translation of the developed methodology (first six months) into excel. This tool is not an end-user-friendly software product, but is aimed at being used by the three partners of SuFiQuaD to make the analysis of both the extreme and representative housing types. A first version of the instrument was delivered in January 2008. This first version showed that it is hard to structure all necessary data of the building, but that the element method is grateful since this method enables to structure all data rigorously. It seems that the tool can be identically structured for both new buildings and renovations, but that the technical solutions for ‘sub-elements’ are different and therefore different data need to be gathered. The tool is structured in such a way that one database is defined which is used to compose the different elements. The data gathered by the different partners only need to be inputted in this database, while the analysis of a certain dwelling only requires input on the other sheets – without altering the database anymore.

Within the ‘**note on quality evaluation**’ the adapted method and translation into excel is described in detail. In the first chapter the adaptations are described which were done in order to avoid double counting and which were needed due to on the revision of the score functions and weighting factors. Furthermore, the results are discussed for the renovated terraced house for one technical solution of all elements. This was included to illustrate the methodology and check the work instrument.

Within the ‘**note on selection of extreme types**’, the choice of extreme types was elaborated. The first chapter focuses on the criteria for selection, while the second describes the four selected dwellings: freestanding house, apartment, newly built and renovated terraced house. These are seen as extreme types since the compactness of the dwellings is extremely different, moreover the terraced houses have sloped roofs and stairs, while the apartment and the freestanding house have a flat roof. For the analysis of the apartment however the shared corridor, roof, stairs and elevator should be taken into account. The third chapter gives an overview of the selected extreme technical solutions: outer walls, load bearing and non-load bearing inner walls, sloped roof, intermediate floors, ground floor and flat roof, heating installation. A final chapter elaborates on the measuring conventions which are differing for the quality evaluation, for the LCA and cost analyse and for the calculation of the heating demand. To overcome the time consuming process of measuring the same building three times, it was decided to use only one way of measuring for the evaluation. A sensitivity analysis of measuring conventions will be done.

Within the “**note on LCC**”, the different sources for financial cost data are described. At first, the initial financial cost is determined. Here, a differentiation is made between labour costs and material costs. The necessary data are taken from the ASPEN database. Secondly, a description is given of the literature sources that are used for gathering of data concerning the operational costs during the use phase of the building. Here, data on energy and transportation costs, as well as financial parameters (such as growth rate and inflation rate) are taken from Belgian statistical sources. Subsequently, literature sources for data on the frequency of cleaning and maintenance, on the cleaning and maintenance activities and on the accompanying costs are described. Finally for the replacements, the expected life span of the different materials and elements is determined based on an extensive literature study.

The additionally developed “**note on Belgian policy**” is focusing on Belgian policy initiatives related to sustainable construction in general. It deals with the different political entities in Belgium, i.e. the Federal level, the Flemish level, the Walloon level and the Brussels Capital level. For each of these, a short description is given of the most important policy documents related to sustainable construction or sustainable development in general. In addition, the role of important governmental institutions is described. Finally, a brief overview of financial incentives to promote

this is the primary focus of the SuFiQuaD project.

The **“interim note for policy preparation”** summarizes the main concept of policy recommendations based on the integrated approach elaborated within SuFiQuaD. It should be seen as an introductory document to a more extended note, which will be delivered at the end of the SuFiQuaD project, entitled “policy preparatory note”. The aim of the latter is to give some recommendations for policy to redirect the housing sector in a more sustainable way. A distinction is made between long term aims and short term actions. A first proposal for a stepwise evolution towards the long term aim is already given within the interim note.

The **“note on selection of representative dwelling types”** describes both the analysis of the current Belgian dwelling stock based on an extensive literature study and the selection of representative dwelling types based on the statistical spread of the Belgian dwellings. The selected representative dwellings are classified according to type, i.e. a freestanding house, a semi-detached house, a terraced house and an apartment, and construction period, i.e. before 1945, between 1945 and 1970, between 1971 and 1990 and between 1990 and 2007. When necessary, distinction was made between the three regions in Belgium, i.e. Flanders, the Walloon Region and the Brussels Capital Region.

The **“note on selection of representative element types”** gives an overview of the common technical solutions for the main building elements within a dwelling, i.e. external walls, internal walls, roofs (inclined and flat), floors (floor on grade and storey floor), windows and doors (external and internal), staircases, railings and balustrades, electricity grid, rainwater drainage and recovery and drives and terraces. These technical solutions represent the basis for further definition and optimisation of representative building elements in the second phase of the project.

Finally, the **“note on technical solutions”** elaborates on the technical solutions for the investigated dwelling types. These technical solutions include the heating system, the domestic hot water system and the ventilation system. Cooling systems are not included, in accordance with the EPBD.

For each of these three technical systems, different possibilities are listed (e.g. type of heating, heat distribution system,...). The combination of these characteristics results in an efficiency of each system. In the last step all the criteria are determined for the technical installations for each dwelling type. This results in a table listing all the selected heating systems, domestic hot water systems and ventilation systems for the different dwelling types with their relevant parameters.

3.2. RESULTS REGARDING THE IMPLEMENTATION OF THE METHODOLOGY TO THE EXTREME DWELLING TYPES

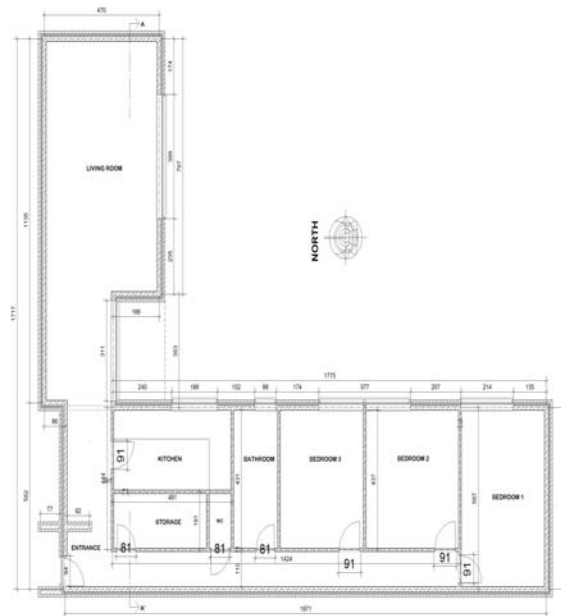
The results regarding the implementation of the methodology to four extreme dwelling types are summarized in a final note. The latter was elaborated in 2 steps, i.e. an “interim note on extreme cases” (68 pages) (July 2008) focussing on a freestanding house and a newly built terraced house and a “final note on extreme cases” (139 pages) (December 2008), in which also an apartment and a renovated terraced house were included. In the process, the methodology has been adapted, the database with financial and environmental costs has been updated and the speed and user friendliness of the programme have been improved.

In the following paragraphs, the most important results are given.

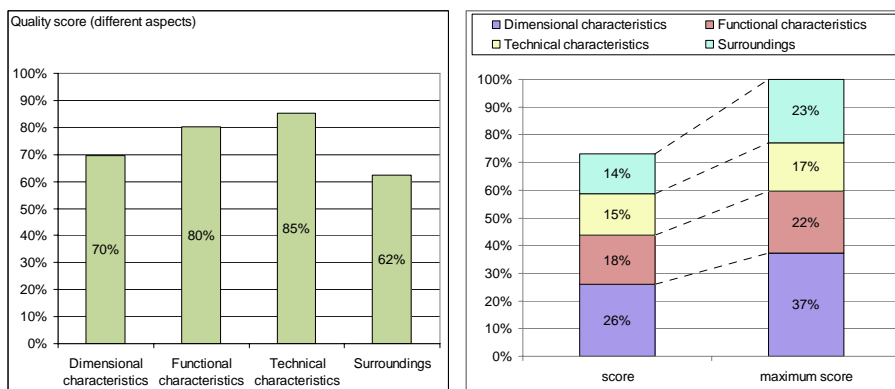
3.2.1. FREESTANDING HOUSE.

The floor plan of the dwelling is shown in the figure below. This dwelling was chosen as an extreme type, because of the fact that it is a freestanding house and its low level of compactness.

For the building elements, again, extreme alternatives were chosen for the technical solutions. For the outer walls, six variants were considered (differing in structure or insulation level or façade finishing). For the floor four alternatives were chosen (differing in insulation level and finishing). For the inner walls, four alternatives were defined (differing in structure and finishing). Both normal and thermally improved double glazing were analysed for the windows. Finally two extreme dwelling life spans were analysed: 60 and 120 years. The remaining elements (foundation, roof edge, window frame, inner doors) were also considered but only one technical solution was included in the analysis. All possible combinations of the above variants were analysed, resulting in 1152 simulations.



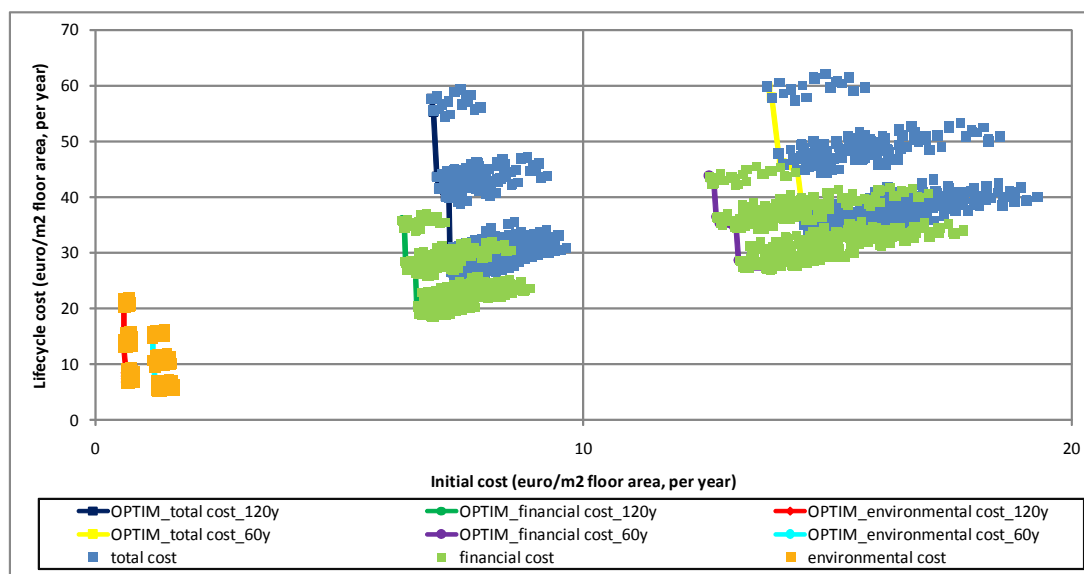
In the graphs below, the results are shown for one variant of the freestanding house. The graph on the left represents the results for the different aspects of the quality evaluation, while the graph on the right represents the obtained weighted score and the maximum score of the different aspects. An identical graph is drawn for all simulations. Not all variants however lead to a different quality score.



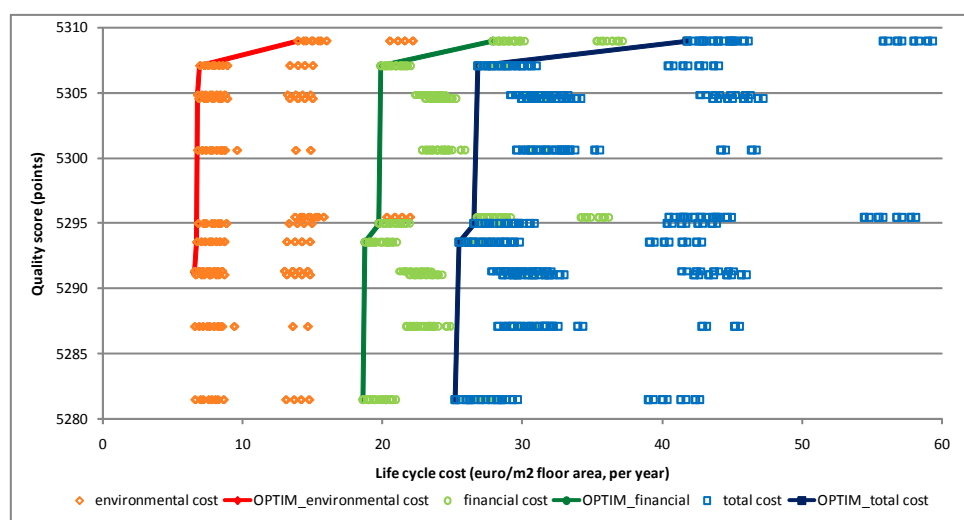
Combining the different alternatives of all elements is automatically executed by a macro. The

computation time however was long: about 24 hours. For the other dwellings, a rationalisation was searched and a reduction of the processing time was achieved (see further). The energy calculations were done all simulations and manually input in the LCA/LCC file.

Finally, an optimisation procedure was run for the results of all simulations by searching for the Pareto front. This was done in two steps. In a first step only the costs were considered comparing the initial cost with the total life cycle cost. Moreover this was done for the financial, for the environmental and for the total (sum of two previous) cost. The Pareto front is again automatically determined by a macro. The results are shown in the graph below.



The results on the different Pareto fronts were analysed in detail and compared with each other. It seemed that decisions based on financial costs were not identical as the ones based on the environmental costs. The total costs were more or less in line with the financial costs, although some additional technical solutions were included in the Pareto front, meaning that different decisions would be taken within a certain financial budget. Moreover, for the financial cost of the Pareto front options for a lifespan of 60 years, the initial cost was by average responsible for 39 % of the life cycle financial cost, while heating during use phase was by average responsible for 40 %. For the environmental cost, it was noticed that the initial phase was by average responsible for 15% of the life cycle environmental cost and heating for 87%. The detailed analysis was described in an intermediate note (July 2008) and presented to the OC in June 2008.



In a second step the Pareto front was searched considering costs and qualities (see graph above).

On the X-axis the life cycle costs were plotted, while the quality score was plotted on the Y-axis. This again for financial, environmental and total costs (sum of two previous). The results revealed that the Pareto front solutions differed from the ones selected based on cost considerations only. For a more detailed description of the results we refer to the intermediate note (July 2008) and the paper entitled “Striving for a more sustainable Belgian dwelling stock”.

In the above described analysis the costs of transportation of the inhabitants during the use phase was not yet included. Based on a literature study by CSTC a transportation scenario was defined for an average Belgian family and processed by the K.U.Leuven to obtain the financial and environmental cost per year, per m² floor area.

The results showed that transportation during the use phase is causing an important environmental and financial cost. The environmental cost equals 6,62€/m² floor area, per year, while the financial cost equals 29,33€/m² floor area, per year. If we again investigate the contribution of the different costs, we conclude, that the initial financial cost is by average responsible for 21% of the life cycle financial cost, heating for 22% and transportation during the use phase 46%. The initial environmental cost is by average responsible for 8% of the life cycle cost, heating for 50% and transportation during use phase for 42%.

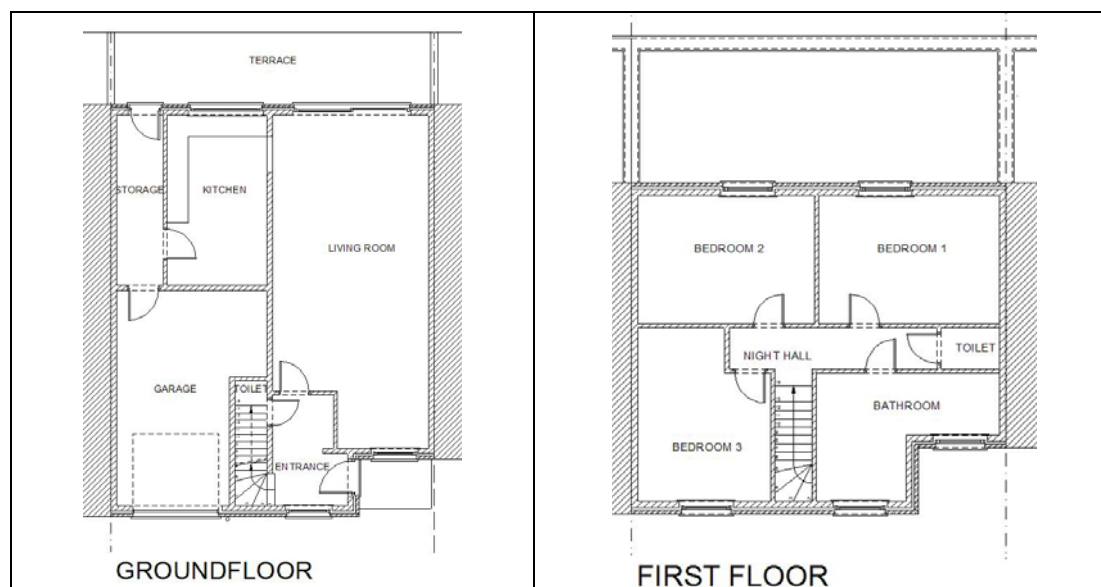
Since transportation during the use phase contributes to a large extent to the life cycle costs, a more detailed analysis will be executed for the representative dwelling types. The aim is to make a differentiation of transport for the different dwelling types and the location of the dwellings. The focus of the research however will be on the dwelling units excluding the transport during the use phase.

The results for the freestanding house were presented to the OC in June 2008 and reported in an intermediate note (July 2008). Moreover, the results were summarized in a peer-reviewed paper which was presented by the K.U.Leuven at the international conference “Sustainable City 2008”.

3.2.2. NEWLY BUILT TERRACED HOUSE.

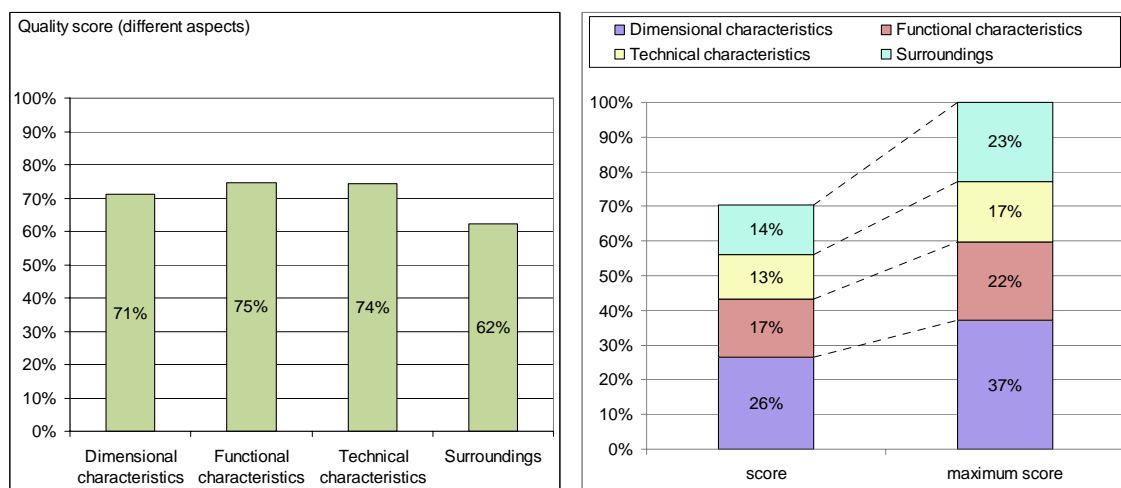
The dwelling has approximately the same total floor area as the previous dwelling, but is two storey's high. The dwelling compactness is therefore much higher than for the first dwelling.

The same approach was used as for the freestanding house. However the processing of the quality assessment and the LCA/LCC calculations were improved to reduce computation time. Finally, elements occurring in the terraced house which were not occurring in the freestanding house were added to the LCA/LCC tool.



The number of simulations has increased in comparison to the freestanding house since more elements were occurring. For the same elements, identical alternatives were considered, again leading to a total of 1152 simulations. Adding the inclined roof (three alternatives) and the intermediate floor (two alternatives) resulted in a total of 6912 simulations. Besides these elements, also the attic floor and the shared walls were assessed, but only one alternative was considered for these.

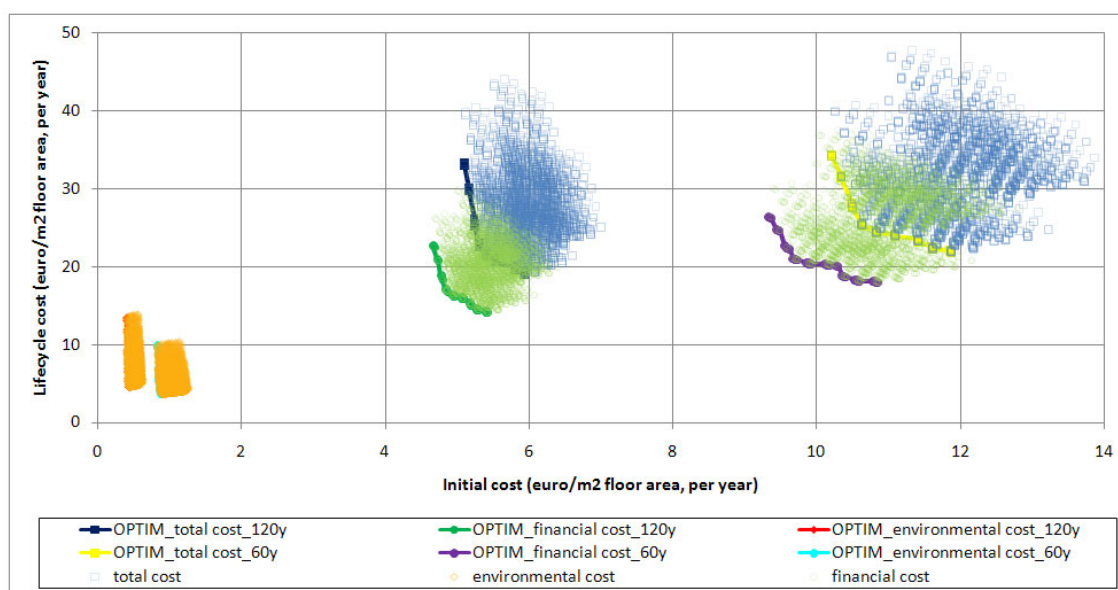
In the graphs below the results are shown for one variant of the terraced house. The graphs show that the total score for the terraced house is lower than for the freestanding house due to a lower score on functional and technical characteristics.



For the LCA/LCC evaluation the total computation time was now reduced by a factor 70 to 2 hours thanks to the use of the optimized spreadsheet. The energy calculations were done separately and manually inputted in the LCA/LCC file.

Finally, an optimisation procedure was run for the results of all simulations by searching for the Pareto front. This was, as reported above, done in two steps. The results are shown in the graph below for the cost optimisation.

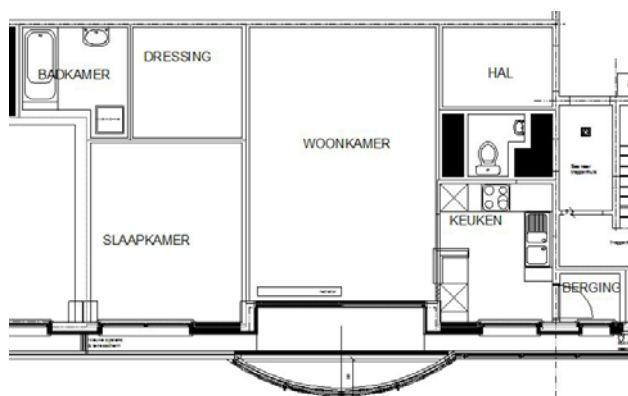
The results on the different Pareto fronts were analysed in detail and compared with each other. If we investigate the contribution of the different phases for the Pareto sets for a lifespan of 60 years, we notice that for the financial costs, the initial cost is by average responsible for 50%, the heating cost for 30%. The environmental initial cost is responsible for 22% and the environmental heating cost 79%. Finally, the total initial cost is by average responsible for 45%, the total heating cost is responsible for 39%.



The optimisation of cost and quality was again considered as well. Again the results revealed that the Pareto front solutions differed from the ones based on cost considerations only. The results for the terraced house were reported in an intermediate note (July 2008). Moreover the results were summarized in a peer-reviewed paper and, if approved, will be presented by VITO on the “6th Australian Conference on LCA” in February 2009.

3.2.3. APARTMENT.

The apartment is located in the centre of the apartment building and its compactness is thus much higher than for the first two dwellings. The floor area is much smaller (69 m²) than for the previous dwellings and the apartment consists of only one bedroom. The plan of the apartment and a photograph of the building is shown below.



The same approach of analysis was used as for the previous dwellings. However, some adaptations were needed for the analysis of the shared space and shared elements of the apartment building. Moreover the quality files have been updated and the calculation of the EOL treatment was revised. Finally, elements occurring in the apartment which were not occurring in the previous dwellings were added to the LCA/LCC tool. It concerns the pile foundation (3 alternatives). Some of the element alternatives were omitted since these revealed irrelevant for application in an apartment building. The total number of simulations resulted in 3072.

The quality evaluation revealed that the total score (approximately 60%) for the apartment is lower than for the previous dwellings due to a lower score on dimensional, functional and technical characteristics.

Finally, an optimisation procedure was run for the results of all simulations by searching for the Pareto front. This was again done in two steps. The results are shown in the graph below for the

cost optimisation.

The results on the different Pareto fronts were analysed in detail and compared with each other. We refer to the report “final note on extreme cases” (December 2008) for a further elaboration. If we investigate the contribution of the different phases for the Pareto sets for a lifespan of 60 years, we notice that for the financial costs, the initial cost is by average responsible for 31%, the heating cost for 11%. The environmental initial cost is responsible for 26% and the environmental heating cost 62%. Finally, the total initial cost is by average responsible for 31%, the total heating cost is responsible for 16%.

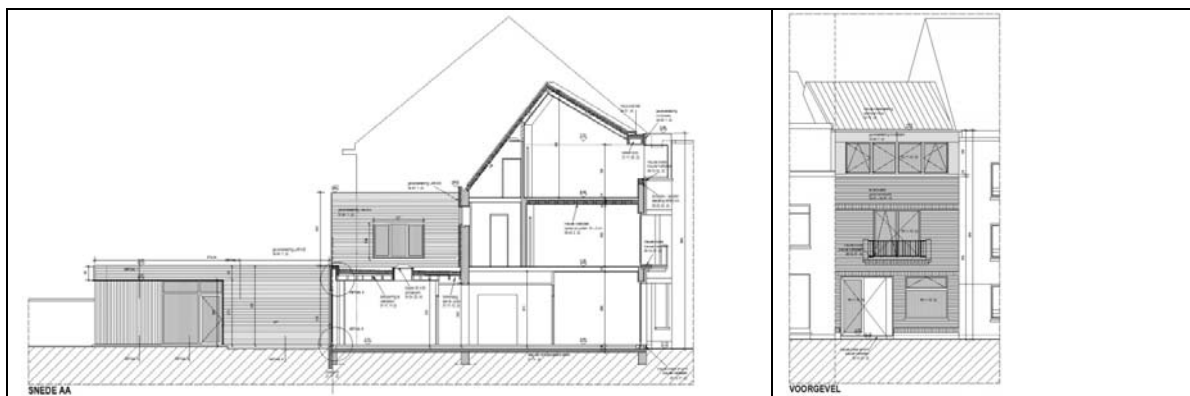
The optimisation of cost and quality was again considered as well. Again the results revealed that the Pareto front solutions differed from the ones based on cost considerations only.



The results of the apartment are presented to the OC in December 2008 and summarized in the final note on extreme cases (December 2008). Moreover, a comparison of the three first dwelling types was presented to the OC in December 2008. Furthermore, this was described in a peer-reviewed paper and, if approved, will be presented on the “3rd CIB International Conference on Smart and Sustainable Built Environments” in June 2009.

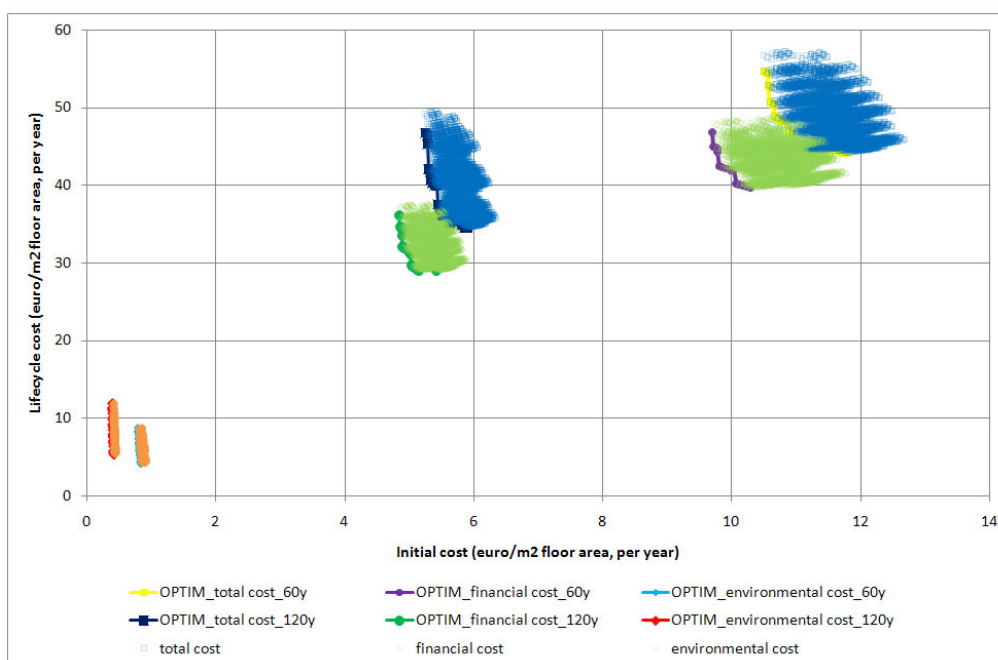
3.2.4. RENOVATED TERRACED HOUSE.

This dwelling was added to the extreme cases in order to address the methodological problem of renovation within the sustainability assessment. The dwelling has a total floor area of 213 m² and is the largest of the four extreme dwellings. The dwelling is represented in section and elevation below. The same approach of analysis was used as for the previous dwellings. However, some adaptations were needed for the attribution a correct part of the investment cost and expected EOL cost of the original dwelling to the previous and new dwelling phase. Moreover the quality files have been updated and the calculation of the EOL treatment and replacements was revised. An extra alternative was added for the intermediate floors, namely floor structure in concrete joist with infill ceramic blocks, covered with a 3 cm reinforced concrete layer. Finally, extra excel sheets were added to enable the calculation of partly renovated building elements (for example, renewing the façade finishing). A financial cost database was created for renovation, since prices differ from new constructions. Moreover, financial and environmental costs were added for demolition activities. The total number of simulations resulted in 20.736.



The quality evaluation revealed that the total score (approximately 64%) for the renovated terraced house is lower than for the two first dwellings, but higher than for the apartment.

Finally, an optimisation procedure was run for the results of all simulations by searching for the Pareto front. This was again done in two steps. The results are shown in the graph below for the cost optimisation.



The results on the different Pareto fronts were analysed in detail and compared with each other. We refer to the report “final note on extreme cases” (December 2008) for a further elaboration. If we investigate the contribution of the different phases for the Pareto sets for a lifespan of 60 years, we notice that for the financial costs, the initial cost is by average responsible for 24%, the heating cost for 19%. The environmental initial cost is responsible for 15% and the environmental heating cost 82%. Finally, the total initial cost is by average responsible for 23%, the total heating cost is responsible for 26%.

The optimisation of cost and quality was again considered as well. Again the results revealed that the Pareto front solutions differed from the ones based on cost considerations only. The results of the renovated terraced house are summarized in the final note on extreme cases (December 2008). Moreover a comparison of the four extreme dwelling types is elaborated in detail in this note.

Finally, we want to remark that for the parameters for which sensitivity analysis will be executed as mentioned in the different notes (amongst others: economic parameters, monetary values of the environmental impacts and weighting factors for the quality evaluation), the values for the basic scenario were assumed for the extreme cases. A sensitivity analysis will only be done for the representative types in the second phase of the project.

4. CONCLUSIONS AND RECOMMENDATIONS

The conclusions which can be drawn based on the results of the first phase of the project are summarized in the following paragraphs. The conclusions based on the analysis of the extreme types, however, should be considered as preliminary, because not all elements have been included in the assessments so far. Moreover, the LCA and LCC database need revision based on more recent available data. Therefore, the evaluation of the methodology and work instrument is more important than the conclusions of the results of the analysis.

4.1. EVALUATION OF THE METHODOLOGY AND WORK INSTRUMENT

The developed methodology enables the evaluation of different aspects of sustainability of dwellings. It not only allows optimising one specific dwelling, but comparison of different dwellings is also possible. Two methodological extensions / improvements had to be developed during the analysis of the extreme dwelling types. The first concerns the consideration of shared space and shared elements in the case of multi-family dwellings (apartment). The second concerns the attribution of the original environmental and financial cost of the dwelling-to-be-renovated to the previous and second dwelling user. For the latter, an approach was chosen which enables to evaluate whether renovation is more sustainable than new construction or not.. Further necessary improvements of the methodology are listed below after the description of the main conclusions of the analysis of the extreme dwelling types.

For the evaluation and improvements of the developed assessment tool, a distinction should be made between what has been done during the first phase and what can only be realised during the second phase of the project.

The improvement of the developed assessment tool has been done gradually during the analysis of the four extreme dwelling types. Following improvements can be mentioned:

- The macros defined at the building level automatically combine each of the different building elements. This led to a very large number of simulations, thus implicating a long computation time for the macros. However, not all combinations were possible or technically feasible (for example an exterior wall with a large width can not be combined with a foundation with a smaller width). Therefore, only the combination of elements which were realistic (possible) were retained with a second macro based on predefined conditions. This was improved for the terraced house by defining a macro for the dwelling level calculations which immediately removes the impossible combinations instead of calculating all and selecting the valid ones in a second step. This led to an enormous reduction of the computation time: from 24 hours to 2 hours for six as many simulations.
- For each dwelling type, extra elements were added which did not occur in the previous dwellings or for which no data were gathered yet before.
- The environmental impact due to the demolition of the building was only included in the last three dwelling types.
- The cleaning and maintenance costs were only added for the analysis of the apartment and renovated terraced house.
- The EOL treatment was improved and the database in the tool was updated accordingly.
- The attribution of shared elements and spaces was added for the analysis of multi-family dwellings.
- Renovation activities were added for the analysis of renovation projects.
- The cost allocation to the initial and second phase of the dwelling in case of renovation was added by taking into account the foreseen lifespan and the lifespan at the moment of

renovation. The methodology however differs from the current proposal at the European level (CEN TC 350) and therefore it will be evaluated if the proposed approach leads to different conclusions than it would be based on the ongoing standardization on European level.

- The quality spreadsheet was improved to enable an easier input for the different alternatives of one dwelling. This led to a reduction in the computation time for the assessment of all alternatives. This was done by defining a macro, which pastes the values in the appropriate cells in the “fiche file”, calculates the results with the “analysis” file and paste the results in a separate file. A list of all alternatives with the quality score is the result.

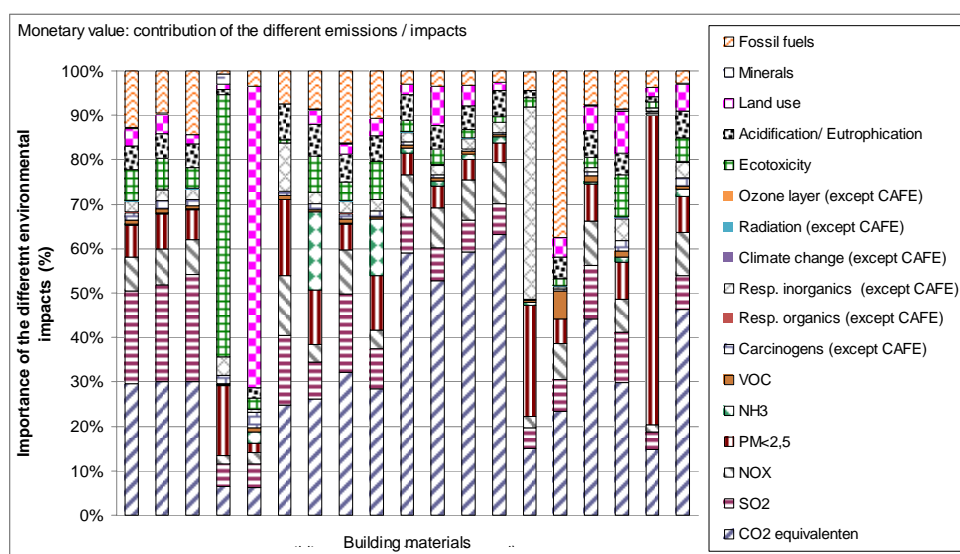
In the second phase of 2 years of the project, the tool will be further developed in order to realise following improvements:

- Extension of the tool with elements, work sections and materials which did not yet occur in the analysed extreme dwelling types.
- The modelling of the building element “windows” will have to be improved. Due to the complexity of the financial cost of windows - depending on the window dimensions and type of window (fixed, turn, turn-tumble, etc) – until now it was not possible to automatically compare different alternatives for the windows. This problem will be resolved by defining specific cost functions (for different materials: aluminium, PVC, Meranti, Afselia) within the Excel tool in order to determine the cost per square meter window based on different input parameters. This should enable to automatically calculate different alternatives using a macro, similar as for the other building elements. The functions are being created at the moment and will be integrated in the tool for the analysis of the representative dwelling types.
- The replacement of work sections is now not dependent on the replacement of other work sections. For example if a wall should be repainted every 15 years, but the gypsum board is renewed every 40 years, then repainting should occur after 15 years, 30 years, 55 years, and so on. At the moment the tool repaints after 15 years, 30 years, 45 years and so on. This should be further improved if proved to be relevant compared to the additional calculation time.
- The replacements taken into account in the tool at this stage, only considers the replacement of an element (or work section) by an identical element (or work section). However, in reality the element (or work section) will in some cases be replaced by a better performing one. A typical example is the replacement of windows which is hardly ever by the same glazing again, or of a boiler replaced by a boiler with a higher efficiency. This should be further improved in the tool.
- A next improvement will be realised by incorporating the energy calculations directly into the tool. In a first step the EPB methodology is being translated into excel. In the first semester of the second phase this will be completed and linked to the LCA/LCC tool in order to avoid the need for the same input twice.
- Finally a link will be established between the quality assessment files and the LCA/LCC file, again to reduce the input time by avoiding double work. However this is not of prior importance since the input time for the quality assessment proved to be minor. Therefore, if time is lacking, this will not be realised.

4.2. PRELIMINARY CONCLUSIONS BASED ON THE RESULTS OF THE EXTREME DWELLING TYPES

1) Contribution of different emissions and environmental impacts

A detailed analysis of the environmental costs enables to analyse the contribution of the different emissions and environmental impacts to the overall environmental costs. This is especially interesting for those materials representing a high environmental cost. There are big differences in how the environmental cost is composed for different building materials.



For a number of materials, CO₂-equivalent emissions are dominating, whereas for others, respiratory effects caused by inorganics (due to emissions of NO_x, SO₂ and/or dust) or respiratory effects caused by organics (due to for example emissions of volatile organic compounds (VOC)) or land use are most important. It therefore seems that governmental policies to stimulate more environmentally materials should not focus on one particular indicator such as CO₂-equivalents, as this might lead to unjustified favouring of some materials over others. For the analysis of the representative dwelling types a sensitivity analysis will be carried out for the contribution of the CO₂-eq. to the overall environmental cost by using both 0,05 euro/kg CO₂-eq and 0,15 euro/kg CO₂-eq. This should clarify if this higher cost would lead to different decisions based on the overall environmental cost.

2) Contribution of different life cycle stages to overall cost

To make a differentiation between the impact of decisions on dwelling level and the impact based on those impacts including choice of dwelling type and dwelling location, the analysis has been executed in two steps. In a first step, transportation of the inhabitants during the use phase of the dwelling was not included.

For the four extreme dwelling types, the total initial costs are nearly always less important than the total costs occurring during the use phase of the dwelling. As we investigate the costs per year, this is of course more pronounced for dwellings with a long service life, where the initial costs are distributed over a longer period. For the dwellings with a service life of 120 years, the initial costs represent between 12 and 32 % of the total costs, depending on the type of dwelling and the technical solutions chosen. For the dwellings with a service life of 60 years however, the initial costs represent between 19 to 55 % of the total costs. The importance of the initial costs rises for dwellings with better insulation, as the costs (both environmental and financial) for heating will reduce considerably.

The costs occurring during the use phase are in nearly all cases the most important ones. The use phase costs can be divided into two parts: heating costs and costs for cleaning, maintenance and replacements. The results for the four extreme dwelling types show that the heating costs are much more important than the cleaning, maintenance and replacement costs for some of the dwelling alternatives, whereas for other alternatives, the costs are almost equally important. Again, this is due to a better insulation of the dwellings.

The end-of-life (EOL) phase was only partially included in the analysis since data for the financial cost for the demolition of the construction and EOL treatment of the demolition waste were lacking. The data for the environmental impact of the demolition processes was not yet incorporated for the freestanding house. It appears that the (environmental) cost for demolition and EOL transport is small in comparison to the other phases. Therefore we could conclude that the demolition phase and transport to the EOL treatment could be omitted from the

analysis without major impact on the results. However four remarks should be made: for the demolition only a rough estimation has been made based on environmental cost / kg demolished material. No differentiation is made between the materials. This means that if the demolition of a certain material causes a lot of dust emissions for example, this has not been taken into account.

Secondly, if the lifespan of the dwellings would be reduced to an important extent, these phases could become important and should then be taken into account.

Thirdly, the demolition works at the moment of renovating the terraced house were accounted as initial costs and not as demolition costs. Only the demolition costs at the end of the lifespan of the dwelling are comprised within the demolition cost. A closer look at the initial environmental costs of the renovated terraced house reveals that on average 19% is caused by the demolition at the moment the dwelling is renovated. Based on this finding, we could conclude that for renovation, the environmental cost due to demolition should be taken into account.

Moreover the demolition cost and EOL costs due to replacements during the lifespan of the dwelling are incorporated in the periodical costs. Therefore the demolition and EOL costs are more important than one should assume at first sight.

Finally, we want to remark that for very well insulated dwellings, the contribution of the heating will be a lot smaller and accordingly the importance of the other life phases will be greater. In these cases it could be important to include demolition and transport to end-of-life treatment to make a correct analysis.

Because of the above remarks, it is suggested to include all phases for the analysis of the first representative dwelling types. Based on the results of a first set of representative types it will be decided if these phases will be further included in the analysis of all representative dwelling types or not.

The cost for EOL treatment is also very small compared to the other life cycle phases. Moreover this resulted for all alternatives in a negative cost (hence a “benefit”) because of the positive influence of recycling or energy recovery processes.

In a second step, the cost due to the transportation of the inhabitants during use phase was included in the analysis. A simplified scenario was used for the estimation of these cost based on the transport scenario of an average Belgian citizen. No differentiation is yet made between the different typologies. This means that the consequences of a certain dwelling type on the surrounding environment (required infrastructure + generation of transport) was not yet considered. The aim was to determine if transport during use phase is important or not.

The results of the analysis showed that transportation during the use phase is causing an important environmental and financial cost, amounting to more than 60% of the total costs. The smaller the dwelling, the more important the transportation is per square meter floor area, per year. Seen the importance of transport to the total cost, it was decided to make a more detailed analysis of transport during use phase, differentiating between location (urban, sub-urban or countryside), between region (Flanders, Walloon region and Brussels) and dwelling typology (influence of density on neighbourhood transport). However, the SuFiQuaD project is not focusing on transportation and therefore only a first estimation will be made based on simplified models.

3) Contribution of the different building elements to overall cost

The analysis of the four extreme dwelling types revealed that the building elements which contribute most to the total initial cost are different for the different dwelling types. For the freestanding house the most important elements are on average the exterior walls (23%) and the flat roof (24%). For the newly built terraced house, the most important elements are on average the ground floor (25%) and the intermediate floor (20%). For the apartment the intermediate floor was by far the most important element (46% averagely), followed by the

interior walls (12% averagely). The most important elements for the renovated terraced house were on average the ground floor (48%), followed by the windows (14%). For the latter dwelling, this is of course highly dependent on the type of renovation work being executed.

These conclusions are however dependent on the form and the size of the dwelling and therefore need to be further investigated. This will be done during the analysis of the representative dwelling types in the second phase of the research.

4) Contribution of environmental and financial cost to overall cost

When investigating the composition of the total costs, it can be concluded from the analysis of the four extreme dwelling types that the financial cost is contributing more to the total cost than the environmental cost. For a lifespan of 60 years, the environmental cost per m² floor area, per year represents by average 10% (apartment) to 21% (freestanding house) of the total costs, compared to 79% (freestanding house) to 90% (apartment) for the financial costs. The minimum contribution of the environmental costs is 8% (apartment) and the maximum 27% (freestanding house). The minimum contribution of the financial cost equals 73% (freestanding house) and the maximum 92% (apartment). All above mentioned percentages concern dwellings with a lifespan of 60 years.

This divergence can be explained by the difference in insulation value of the building skin and the fact that the environmental cost is higher for the heating demand than for the initial phase, while for the financial cost the opposite is true.

For the extreme types, we could observe a big difference in relative importance of the different life phases for the environmental costs on the one hand and the financial costs on the other hand. While for the environmental cost, heating is the most important aspect, for the financial cost, cleaning, maintenance and replacements are most important. Moreover, heating is on average least important if only financial costs are considered.

A consequence of the above is that if the environmental costs would be internalised in the financial costs, heating would gain more importance than is the case now. An optimisation of the dwelling stock based on environmental cost would mainly focus on heating first, while an optimisation based on financial cost would mainly focus on cleaning, maintenance and replacement costs, followed by initial costs.

However, since the total costs are mainly determined by the financial costs, the optimisation based on total costs will mainly focus on the three phases: initial cost (33%), cleaning, maintenance and replacements (35%) and heating (33%). The percentages mentioned are the contribution of the total cost of these phases to the life cycle total cost for a lifespan of 60 years (average over all Pareto subsets of all dwelling types). For solutions outside the Pareto front the situation can be completely different.

5) Contribution of environmental and financial cost to the total cost of the different life phases

A closer look at the contribution of the environmental and financial part of the total costs of the different phases revealed the approximately the following percentages (average):

- Initial phase: FC: 90% - EC: 10%
- Cleaning, maintenance and replacements: FC: 96% - EC: 4%
- Heating: FC: 62% - EC: 38%

Internalising the environmental costs in the financial costs, therefore will mainly influence the energy prices (with 40%) while this will have a smaller impact on (processed-) material costs (10%) (including labour cost).

6) Quality evaluation of the different dwelling types

A difference in quality was revealed between the different dwelling types. The freestanding house was obtaining the highest average score, followed by the newly built terraced house, then the renovated terraced house and finally by the apartment.

Moreover, all dwellings score approximately identical for the surroundings and for the technical characteristics (based on the made hypotheses). The lower score for the apartment was due to a lower score on the dimensional and functional characteristics.

However, the quality evaluation as assessed for the analysis of the extreme dwelling types, was not considering different profiles of inhabitants. If this would be taken into account, it would probably lead to the conclusion that the apartment would score best for some profiles of inhabitants.

Therefore (and also based on the suggestions of the follow-up committee) it was decided to elaborate a limited set of different profiles for the analysis of the representative dwelling types. This differentiation will represent society better than the one “average” profile considered for the extreme dwelling types.

No big differentiation was noticed between the quality score of the different alternatives of the same dwelling. This can be explained by the fact that only alternative solutions of the constituting elements were investigated. No alterations were made to the form or size of the dwelling. The latter two will presumably influence the quality score to a larger extent. This will be further analysed when evaluating the representative dwelling types in the second phase of the project.

7) Differences between LCA, LCC and quality assessment results

The decisions based on the optimisation of the different parameters (environmental cost, financial cost, total cost and quality) revealed not to be always in line.

It seemed that decisions based on financial costs were not identical as the ones based on the environmental costs, whereas the decisions based on total costs were more or less in line with decisions based on the financial costs. The steps to evolve from the reference to the final dwelling were however not always identical. This means that within a limited budget, the measures taken based on total cost can differ from the measures taken based on financial cost only.

Furthermore, the optimal solutions based on cost optimisation were not identical to the optimal solutions taking into account the quality of the dwelling. This can be explained by the fact that from quality perspective, there are other priorities to be considered than those which can be addressed by cost optimisation (e.g. ease of maintenance, acoustical performance).

4.3. RECOMMENDATIONS BASED ON THE RESULTS OF FOUR EXTREME DWELLING TYPES

The following improvements of the methodology seem important based on the experience of the analysis of the four extreme dwelling types:

1) Recommendation 1 – Improve modelling of transportation of inhabitants:

Since transportation during the use phase contributes to a large extent to the life cycle costs, a more detailed analysis should (and will) be executed for the representative dwelling types. The aim is to make a differentiation of transport for the different dwelling types and the location of the dwellings. However, transportation is not the main focus of this project, and therefore will be limited to some rough estimations based on simplified models.

2) Recommendation 2 – Simplify detailed description of building elements:

The detailed description and quantification of the different technical solutions for the building elements is a time-consuming activity. However, some of the constituent materials only represent a minor fraction of the overall environmental and financial cost. For the representative types first rough estimations of the amount of constituting materials will be made and based on these the environmental and financial cost will be calculated. If some of the materials prove to be unimportant these will be left out of the analysis (but transparently reported). Only for the materials of importance a more detailed investigation of the amount will be done. This will lead to a more efficient use of the computation time.

3) Recommendation 3 – Inclusion of life cycle phases and building elements in the calculations:

Based on the analysis of the extreme dwelling types, we cannot yet conclude if some of the life cycle phases can be excluded from the analysis. The main reason is that low energy houses or passive houses have not yet been analysed. For these extremely insulated dwellings, the relative contribution of the different life cycle phases will most probably differ from the extreme dwelling types considered.

This will be further investigated during the first months of the second phase and based on these results it will be decided if some of the life cycle phases can be omitted. This omission would benefit the reduction of the time needed for data collection.

4) Recommendation 4 – Optimisation at the element level:

The number of combinations for the different dwellings revealed to increase exponential. Therefore it seems unavoidable (to reduce computation time) to make an optimisation at the element level first, before all considered element solutions are combined at the dwelling level. However, interaction of the different elements should not be neglected during this first optimisation step. For example, for better insulated dwellings, the improvement of the efficiency of the heating installation will have a lower impact on the overall cost than for the dwelling with lower insulation level. For the energy calculations at the element level, only transmission losses can be addressed. This will be done based on the equivalent degree-days.

5) Recommendation 5 – defining more specific Pareto front conditions:

For the determination of the Pareto front solutions, we started with a reference dwelling, defined by the lowest initial cost (in the case of cost-optimisation or lowest total cost in the case of Q/C-optimisation) and searched for the solutions with the highest life cycle cost decrease for the smallest extra investment cost (in the case of cost-optimisation or highest quality increase for lowest total cost increase in the case of Q/C-optimisation). However the analysis of the extreme dwelling types revealed that the last Pareto front solutions resulted in a high increase of the investment cost for a small decrease of the life cycle cost. The question has risen if it is worthwhile to take these last measures. Based on these findings, it was decided that extra conditions are needed to determine which minimum extra reduction of the life cycle cost should be achieved for the extra investment made (or thus: what should the minimum inclination be (marginal efficiency) on the Pareto front). This will be further elaborated during the analysis of the representative dwelling types.

6) Recommendation 6 – considering all or only convex lines on the Pareto front:

For the analysis of the extreme dwelling types, all possible solutions (without any restriction) which (starting from the reference) led to a lower marginal life cycle cost for the smallest increase in investment cost were selected. However, if there is no budget restriction, we could reduce the number of Pareto front solutions by requiring that the lines on the Pareto front should be convex. Both will be investigated and compared for the analysis of the representative dwelling types to check if this reduction is important (for saving computation time) or not.

7) Recommendation 7 – analysis based on financial, environmental or total cost?:

For the analysis of the extreme dwelling types, we always made an analysis based on total cost, financial cost and environmental cost. However, considering financial cost only does not seem to contribute to the improvement of the sustainability of the dwelling stock. Moreover considering environmental costs only, is only relevant if the dwelling owner has no financial budget restrictions at all. Therefore the analysis of the representative dwelling types will mainly be based on total costs. The differentiation between financial and environmental cost will only be done for some specific cases to make a detailed analysis of both separately if this seems relevant.

5. FUTURE PROSPECTS AND PLANNING FOR THE SECOND PHASE

The second phase of the project consists of the application of the developed ‘integrated’ approach to representative housing typologies.

It is a fact that the Belgian scene is composed of different housing types. Housing type, location and technical choices for building elements are interrelated. Each type will generate other requirements at the level of the building element: acoustical and thermal performance, fire-resistance, maintenance, structural safety, etc. Each type will also have other qualities: access to garden, expandability, thermal compactness, floor/terrain ratio, requirements for public infrastructure, etc. Decisions on housing type and all related aspects are in most cases taken by non institutional actors whose insight in the multitude of consequences are limited. Phrased as a caricature: the average builder looks for a cheap plot (that will be far from any centre and generate a lot of infrastructure costs and future transport), builds a bungalow at a low price (this will generate a lot of heating costs and - due to savings on investment costs - a lot of maintenance and repair) and if he/she wants - at a certain moment in life - to move to a smaller easy-to-maintain apartment in a more central location, the sales value turns out to be relatively low.

Representative housing types have been selected in the first phase of the project based on previous research (amongst other, research by the three partners) and a literature study: existing surveys, scientific and commercial journals, statistics, etc. For each selected housing type, a reference case (reference location, reference orientation, reference technical solutions, reference lifestyle of the tenants, reference lifespan of the building, reference maintenance and replacement patterns,...) will be defined and analysed with the elaborated work instrument.

In a next step improvements (of location, orientation, lifestyle, spatial characteristics, technical solutions,...) will be listed for each housing type and evaluated by analysing the relative improvements by the optimisation approach as explained before.

Based on the results not only the improvements can be organized by efficiency, but the different housing types can be compared as well.

The elaborated methodology and analysis of the housing typologies should allow answering the following question: ‘starting from a basic solution, how can the limited budget best be spent taking into account environmental effects and qualities?’ Translating the insights into an operational policy is the next step.

To reach this aim the objective within this research is to elaborate a preparatory policy document by listing possible and priority policy measures for a sustainable development of the (building and) housing sector. These will be evaluated concerning feasibility, advantages and drawbacks.

It should be investigated for example whether certain materials or building elements or even design decisions (as amount of glazed surface) can be forbidden or enforced since the choice leads to unacceptable environmental costs. For many more cases it is imaginable that a tax and subsidy system could internalise all external effects.

The activities of the second phase of the project are grouped into a number of work packages:

Work package 1: Co-ordination (continued)

All research partners involved are responsible for the quality concerning the content of the results. This will be guaranteed by regular, interim meetings of the research partners organized by the project co-ordinator.

The co-ordination of the project rests at the research group Design and Building Methodology of the Department of Architecture, Urban Design and Planning (ASRO) of the K.U.Leuven. The co-ordination is supervised by Prof. dr. ir. arch. F. De Troyer and ir. arch. K. Allacker.

Work package 5: Elaboration refined version methodology + work instrument

- Task 5.1: Elaboration refined version methodology
- Task 5.2: Elaboration refined work instrument

During the first semester of year 3, the K.U.Leuven is responsible for the refinement of the methodology and the work instrument based on the findings of the test application (in collaboration with the two other partners). In the second semester of the fourth year a final refinement will take place based on the application to the representative types, the approach will be documented and future prospects will be evaluated.

Work package 6: Data inventory and elaboration (representative types)

- Task 6.1: Data inventory and elaboration on LCA
- Task 6.2: Data inventory and elaboration on LCC
- Task 6.3: Data inventory and elaboration on quality

Work package 6 will continue in year 3: VITO will coordinate the data inventory and elaboration in relation with the objectives of this proposal (the representative types). During the first semester of the third year CSTC and VITO will continue with the gathering of the LCA data focusing on the representative types, while K.U.Leuven will continue with the inventory and elaboration of the LCC and quality data in this work package for the representative types.

Work package 7: Application of methodology – analysis of representative types

- Task 7.4: Analysis of representative types (reference case + improvements)

With CSTC as work package leader, the three project partners will continue the analysis of the representative types during years 3 and 4.

Work package 8: Policy preparation

The policy preparation will be carried out during the last semester of the fourth year. VITO, the work package leader, will be assisted mainly by CSTC, and to a lesser degree by the K.U.Leuven.

6. PUBLICATIONS

6.1. PUBLICATIONS OF THE TEAMS

6.1.1. PEER REVIEW

K.U.Leuven :

- paper : K. Allacker, F. De Troyer, Integrated sustainability assessment of dwellings in the Belgian context, submitted for SASBE09 (3rd CIB International Conference on Smart and Sustainable Built environments), June 15-19 2009, Delft, The Netherlands (abstract accepted, paper submitted for peer reviewing)

6.1.2. OTHERS

K.U.Leuven :

- Presentation : K. Allacker, *SuFiQuaD – Sustainability, Financial Cost and Qualities of Dwelling types*, Perspective EEIG, 9 February 2007, Antwerp, Belgium.
- Extended abstract and Presentation : K. Allacker, F. De Troyer, *Optimising the Belgian dwelling stock by integrating environmental and financial constraints*, Studiedag Onderzoekscentrum “Space and Society”, 21 March 2008, Leuven, Belgium.
- Presentation : K. Allacker, F. De Troyer, *SuFiQuaD – Sustainability, Financial Cost and Qualities of Dwelling types*, Transitie arena, 23 April 2008, Brussels, Belgium.
- Presentation : F. De Troyer, *Duurzaam materiaalgebruik en SuFiQuaD*, PMC-BMP, 17 December 2007, Brussels, Belgium.
- Presentation : F. De Troyer, *SuFiQuaD – Sustainability, Financial Cost and Qualities of Dwelling types*, Workshop BELSPO – SSD, 6 November 2008, Brussels, Belgium.

CSTC :

- Presentation : K. Putzeys, *Duurzaam bouwen – een geïntegreerde benadering*, BIS beurs, 12 October 2007, Gent, Belgium.

VITO :

- Presentation: C. Spirinckx, « *Cursus duurzaamheid en hogere milieukwaliteit voor federale ambtenaren: Levenscyclusanalyse in de bouwwereld* », organised by OVI (Federale Overheid), 11 October 2007, Brussels, Belgium
- Presentation: C. Spirinckx – « Sustainable Building - Search for an Integrated Method to Evaluate the Sustainability of Dwelling Types in Belgium », European Roundtable on Sustainable Consumption and Production, ERSCP2008, September 2008, Berlin, Germany.
- Presentation: T. Geerken, C. Spirinckx, A. Vercalsteren, Sustainable Building: The Search for an Integrated Method to Evaluate the Sustainability of Different Dwelling Types, 6th Australian Conference on Life Cycle Assessment, February 16th - 19th, 2009, Melbourne, Australia()

6.2. CO-PUBLICATIONS

6.2.1. PEER REVIEW

K.U.Leuven, VITO :

- abstract submitted (in reviewing process) to be accepted for further elaboration as paper in the International Journal of Life Cycle Assessment ; K. Allacker, F. De Troyer, T. Geerken, C. Spirinckx , A. Vercalsteren, *Sustainable Building - Search for an Integrated Method to Evaluate the Sustainability of Dwelling Types in Belgium*.

K.U.Leuven, VITO, CSTC :

- Paper : K. Allacker, F. De Troyer, C. Spirinckx, L. De Nocker, A. Vercalsteren, B. Tomasetig, K. Putzeys, Striving for a more sustainable Belgian dwelling stock, Proceedings of Sustainable City

2008, pp. 10. (published in September by WIT Press).

VITO, CSTC, WTCB :

- paper submitted (in reviewing process) : C. Spirinckx, A. Vercalsteren, K. Putzeys, K. Allacker and F. De Troyer, Sustainable building: the search for an integrated method to evaluate the sustainability of different dwelling types, submitted for the 6th Australian Conference on LCA, February 18 -20 2009, Melbourne, Australia (abstract accepted, paper submitted for peer reviewing)

6.2.2. OTHERS

K.U.Leuven, VITO, CSTC:

- Poster: De Troyer, F., Allacker, K., Spirinckx, C., Vercalsteren, A., Putzeys, K., *Sustainable Building – Search for an integrated method to evaluate the sustainability of dwelling types*, ERSCP07, Basel, Switzerland, June 2007, (presentation + poster as result of workshop).

- SuFiQuaD - Sustainability, Financial and Qualityevaluation of Dwelling types, PREPARE newsletter, a European network on Preventative Environmental Protection Approaches in Europe, Newsletter 3, pp. 11, July 2008.

- SuFiQuaD - Sustainability, Financial and Quality evaluation of Dwelling types - ‘Evaluatie van verschillende woningtypes op gebied van milieu-impact, financiële kost en kwaliteit’, vaktijdschrift DIMENSION, September 2008 by FCO MEDIA, Filip Cossement Blvd des Canadiens 118, 7711 Dottignies, Belgium.

K.U.Leuven, VITO:

- Presentation + extended abstract: Allacker, K., Spirinckx, C., *Development of a methodology to optimize dwelling types in Belgium*, Cycle07, Montréal, Canada, October 2007.

- SuFiQuaD - Sustainability, Financial and Quality evaluation of Dwelling types, in PREPARE Newsletter N°3, 2008, Preventative Environmental Protection Approaches in Europe, on page 11, National Highlights Belgium, 2008

- Contribution in Annual VITO report 2008 (in progress)

6.3. OTHER ACTIVITIES

- Workshop “Sustainable Building - a search for an integrated method to evaluate the sustainability of dwelling types”, organised by K.U.Leuven, VITO and WTCB at the 11th European Roundtable on Sustainable Consumption and Production (ERSCP) in Basel, Switzerland, June 21, 2007.

= > Introduction to the workshop was given by means of a presentation by Karen Allacker and Carolin Spirinckx on the SuFiQuaD project.

= > The results of the workshop were summarized and presented at the ERSCP2007 by means of a poster.