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DoW	<p>T5.3: Energy Simulation and optimisation tool: This task will integrate energy simulation and optimisation tools with the tools developed in T5.1 using the 3DMaps GIS platform via applicable open standards, such as KML and GML. The energy simulation tools will enable the identification of baseline energy emissions. The tool will be developed to enable automated comparison between base line energy emissions and CO₂ emissions and the emissions/energy reduction targets to be reached as identified in the case studies. A trade-off or optimisation tool will also be developed and integrated with the 3DMap GIS platform supporting open standards. This trade-off or optimisation tool will enable the optimisation of energy efficiency and renewable energy interventions by supporting trade-offs between conflicting social economic political and environmental constraints within planning and design practice. The optimisation approach adopted will support stakeholders’ needs in the case study areas identified by WP2 and detailed in WP6. The approach adopted will utilise multi-criteria decision analysis (MCDA), also known as multi criteria decision making (MCDM). The tool will be integrated in the SEMANCO platform.</p> <p>D5.3 Energy simulation and trade-off visualisation tool: A prototype tool which integrates current energy simulation and optimisation tools and approaches with the prototype building stock modelling tool developed in T5.1 and the Semantic Energy Information Framework (SEIF)</p>				
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EXECUTIVE SUMMARY

This report presents the work done in Task 5.3 *Energy simulation and optimisation tool* of the SEMANCO project. This principally included the development of fully integrated intervention assessment tools for each of the three case studies within SEMANCO, and a multi criteria tool for considering the effects of different energy efficiency interventions in the built environment that can be applied in each of the three case studies. Therefore the work conducted within Task 5.3, and described in the current deliverable, focused on:

- 1) The extension of the tools developed in Task 5.1 *Building stock energy modelling tool* to enable the specification of interventions to improve the energy consumption of buildings or urban areas and for the quantitative calculation of the results of such interventions.
- 2) The development of a multi criteria based trade off/optimisation tool to help users to decide which of a set of differing potential interventions provide the best option.

The specific characteristics of the tools which are specific to each case study are:

- In the case of Manresa the baseline energy efficiency tool, URSOS, assesses the individual energy efficiency of the houses within an area and how the shadows cast by the buildings affect the costs for cooling and heating. As with the Newcastle tool, the improvement tool focuses on considering the effects of potential fabric refits on the energy efficiency of these houses.
- In the case of New Harbour in Copenhagen the principal focus of the case study is on considering the energy efficiency of proposals for constructing new urban areas. In consequence the improvement tool focuses on evaluating the effects of measures regarding sustainable energy supply and energy savings that might be applied when constructing that new urban area.
- In the case of Newcastle the focus is on considering the energy efficiency of individual houses in detail, the energy efficiency interventions are focused on improving the fabric of those houses.

The multi criteria based trade off tool which has been developed in the work of Task 5.3 is generic. As such it is applicable across all three case study areas¹. However the tools for specifying potential interventions to reduce the baseline energy consumption of a given area are by necessity case study specific. In each case the task of optimisation is supplied by using the quantitative answers from these tools, and the qualitative information from the multi criteria tool, to pick the best set of refits to apply.

The integration of the tools presented in this report lies in Task 5.4 *Prototype Integrated Platform* and Task 5.6 *Integrated Platform*. At the moment of writing this report, each of the tools have been completed and integrated within the current version of the SEMANCO platform.

¹ The case study areas are described in Deliverable 2.1 *Report of the case study and analysis*.

1 INTRODUCTION

1.1 Purpose and target group

The primary purpose of this deliverable is to describe the software developed during the course of Task 5.3 *Energy simulation and optimisation tool*. The task involved two major areas of software development:

- The development of *intervention assessment* tools for energy simulation and optimisation for each of the three case studies within SEMANCO,
- The development of a multi criteria based decision support tool for evaluating both qualitative and quantitative aspects when considering which refits should be made to buildings or urban areas. This tool can also be used for supporting decisions related to the development of new urban areas.

In the case of the tools for energy simulation and optimisation, the underlying concepts remain comparable for each of the case study areas. However the differing user requirements, as outlined in Deliverable 6.1 *Defining the problem domain and scope of the tools within the case study scenarios*, mean that the concrete realisation of these ideas within each case study differ:

- In the case of Manresa the baseline energy efficiency tool, URSOS, assesses the individual energy efficiency of the houses within an area and how the shadows cast by the buildings affect the costs for cooling and heating. As with the Newcastle tool, the improvement tool focuses on considering the effects of potential refits on the energy efficiency of the individual houses within the model.
- In the case of Copenhagen the principal focus of the case study is on considering the energy efficiency of proposals for constructing new urban areas. In consequence the improvement tool focuses on evaluating the effects of measures regarding sustainable energy supply and energy savings that might be applied when constructing that new urban area.
- In the case of Newcastle the focus is on considering the energy efficiency of individual houses in detail and so the energy efficiency interventions focus on considering the application of potential refits to the fabric of those houses.

Each of the intervention assessment tools have been developed and integrated within the current version of the SEMANCO integrated platform. In addition, a multi criteria decision support tool has been developed. Unlike the intervention assessment tools, the multi criteria decision support tool applies identically across all three case study areas.

It uses multi criteria decision analysis techniques in order to enable people to simultaneously compare multiple distinct options for intervening against the baseline. This can involve considering both multiple simultaneous quantitative criteria and ones with a more qualitative basis.

The target groups are the users of the SEMANCO platform (energy consultants, engineers, planners) who can use the tools presented in this document to explore measures aimed at improving the energy efficiency of selected urban areas.

1.2 Contribution of partners

The University of Teesside (UoT) has been responsible for the specification and development of the intervention assessment tool related to the Newcastle case study. RAMBOLL and FORUM/CIMNE were responsible for specifying the improvement tools for their respective case

study areas, while FUNITEC developed and integrated these tools. UoT also lead on the production of this report and the co-ordination of the work between partners related to the tools developed in Task 5.3. CIMNE was responsible for the design of the MCDA tool described in Chapter 4 and FUNITEC developed it and implemented it in the integrated platform.

1.3 Relations to other activities in the project

The work carried out in Task 5.3 builds directly on work developed within Task 5.1. The software produced within it provides a major component of the overall SEMANTCO integrated platform and thus contributes directly to both Task 5.4 *Prototype of the integrated platform* and Task 5.6 *Integrated Platform*. In addition it will directly contribute to any future demonstration and user testing activities in Work Packages 6 and 8.

In forming part of the integrated SEMANTCO platform it builds on the semantic framework developed in WP3 *Energy Data Modelling* and WP 4 *Semantic Energy Information Framework*. The development work in the task was guided by the requirements/case study descriptions produced by WP 2 *Case Studies*, WP6 *Enabling Scenarios for Stakeholders* and WP8 *Implementation*.

1.4 Structure of the document

The current document follows the current structure:

- Chapter 2 focuses on describing the intervention assessment tools. It starts with a description of how these tools build on, and work together with, the tools from Deliverable 5.1 *Building extraction and classification tools*. Following on from this it presents sections describing each of the intervention assessment tools. These are presented consecutively, with a section devoted to describing the details of each.

Since the nature of the baseline energy measurement in each of the three case study areas varies the intervention assessment tools vary to reflect these differences. These differences are explained and reflected in the initial parts of these sections before the tools are later described in more detail.

- Chapter 3 focuses on describing the multi criteria based decision support tool. This starts with a brief coverage of the theoretical basis for this tool, follows by describing the tool and finishes with examples of the tool in use within the SEMANTCO integrated platform.
- Chapter 4 contains the conclusions to the document.
- Appendix A contains some additional background to the multi criteria decision support tool.

2 INTERVENTION ASSESSMENT TOOLS

2.1 Introduction

In order to fully understand the tools developed within Task 5.3 it is necessary to first understand their overall purpose within the SEMANCO integrated platform. This, in combination with the tools developed as part of Task 5.1, is to enable users to decide on what energy related interventions they would like to make to a given urban area.

Facilitating this requires that the users can perform the following tasks:

- Attaching baseline energy measurements to the respective urban energy models,
- Proposing certain sets of interventions to modify the energy use of the model, and
- Judging which of the proposed sets of interventions actually works best when judged against a set of specified criteria.

In turn, the tools for establishing baseline energy measurements were developed in Task 5.1 and presented in Deliverable 5.1 *Building Extraction and Classification Tools*; the tools for proposing and evaluating sets of interventions – henceforth *intervention assessment tools* – are described in Chapter 3 of the current document and the tool for supporting decisions between different sets of proposed interventions is described in Chapter 4 of this document.

The task of tying the functionality of the three sets of tools described above falls to the SEMANCO integrated platform. The principal responsibility for the development of this platform within the SEMANCO project falls to Tasks 5.4 *Prototype of the Integrated Platform* and 5.6 *Integrated Platform*.

The current section therefore presents only the basic outline of the framework in which these tools operate. A fully detailed description of the integrated platform, including how it integrates the operation of all of the tools developed within the SEMANCO project, can be found in deliverables D5.4 *Prototype of the Integrated Platform* and D5.6 *Integrated Platform*.

The basic way in which the integrated platform supports the combination of these tools is by using the following arrangement of layers within its user interface:

- Each case study area is associated with one or more *urban energy models*. An urban energy model contains the baseline data relating to that case study area. This includes both the three dimensional model of the urban area and any baseline energy measurements which have been previously attached to sections of that model.

The baseline energy modelling tools developed within Task 5.1 are applied at the level of the urban energy model – houses/areas of the city are selected, rated and this rating is then stored to the overall map of the city and reused whenever work on that city is desired.

Conceptually, the ratings within the urban energy model correspond to the current reality within the city and so are only updated to reflect changes in the actual buildings within that city. In the case of Copenhagen there are no existing buildings to model, so the baseline corresponds to a chosen proposal for constructing the given urban area.

- When a user, such as a social housing provider or an urban planning office creating a new plan, wishes to consider the effects of different interventions within a given area of one of the urban models they create a *plan*.

Formally the process of creating a plan corresponds to the user selecting the area within the urban model for which the user is interested in considering energy efficiency. Depending on the nature of the case study, this area might either be an actual geographical area or a given set of discrete houses.

No attempts to alter the energy efficiency of the areas/houses within the plan itself are considered at this stage.

- Each plan then has a set of *projects* attached. Each individual project corresponds to a specific, concrete proposal for intervening in the area selected within the plan in order to increase its energy efficiency. It is at this stage that the intervention assessment tools developed as part of Task 5.3 are used.
- Finally, once a plan has a set of several projects attached to it, the user can switch back to the plan interface and use the multi criteria tool developed as part of Task 5.3 to help to compare the interventions contained within each project. This then lets them decide which project they would prefer to enact in practice.

A summary of this overall flow is presented in Figure 1 below:

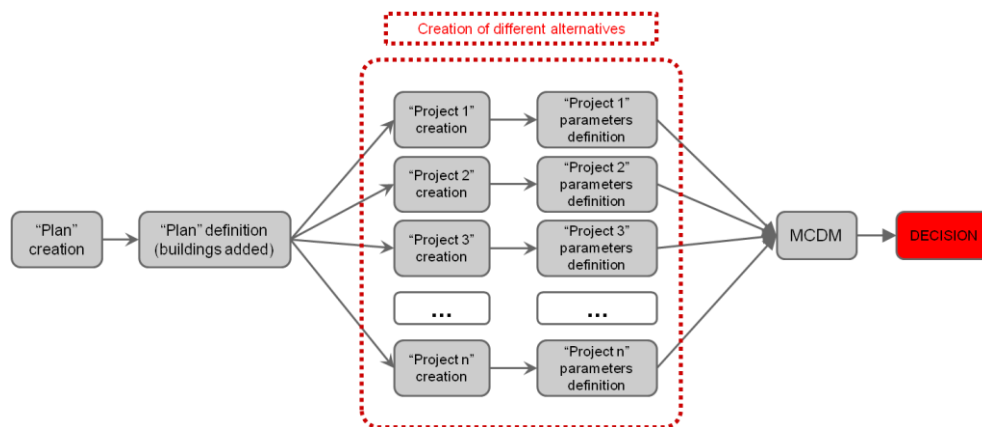


Figure 1. Workflow for decision making within the platform

2.2 The Manresa Tool

2.2.1 Case study considerations

The case study described in the city of Manresa has been contextualised under the coverage of the Spanish situation. As a member of the European Union, Spain is on its way to developing all EU Directives addressing the issue of Energy Performance of buildings. Nowadays the most ambitious challenge is this will arise in 2020, by which time it is envisaged that all new buildings should be Nearly Zero Energy Buildings.

The current building situation in Spain concerning its energy performance is quite disturbing. Buildings are responsible of 17% of the total energy consumption, and furthermore, they are also responsible of nearly 20% of GHG emissions.

More than 60% of the current building stock in Spain was built before 1980 (before the application of any sort of legislation regulating the use of isolation in building construction), and even the more recent buildings, built under the commitment of the CTE (Technical Building Code), which represent around 7% of the total, are far away from the NZEB standard.

The tools developed during Task 5.1 *Building stock Energy Modelling Tool* integrated within the SEMANTO platform are meant to address the most important contributors to the described group. That is calculating the energy performance of a building while it is occupied and in use,

which represents around 64% of the total CO₂ emitted during the whole lifetime of a building, including its design, construction and demolition. Furthermore, the interfaced software was chosen because of the outputs obtained, which focus on describing the energy needed for heating and cooling spaces, and for domestic hot water usage. These concepts represent almost 70% of energy used in the domestic environment.

After the integration of the URSOS software, the visible result of this work takes the shape of a form interfacing the URSOS calculation with some other minor calculations as well (Figure 2). This form includes a set of all the input parameters needed to perform those calculations, both creating a file to be executed by the URSOS engine calculation, or performing other simpler calculations outside this software (basic Excel sheets).

Figure 2. Image of the form integrating URSOS and other calculations at building level

The result of performing those calculations is a set of indicators estimating how much energy the building will use in a typical year. The results are presented in terms of energy need, energy demand, CO₂ emissions and energy cost (Figure 3). Those parameters are provided as aggregated results in a yearly basis, but also disaggregated using a simple calculation, showing the energy performance related to the basic surface unit (m²). This simple step provides the first approach to allow the user linear comparisons through different buildings, and also sets the first step to reach the urban level desired on the project.

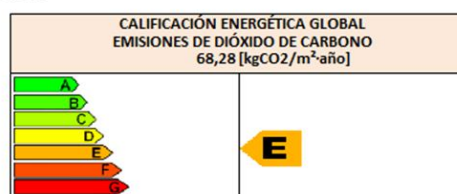
Disreggregated Results		Energy need (kWh/m ² y)	Energy demand (KWh/m ² y)	CO2 emissions (KgCO2/m ² y)	Energy Cost (€/m ² y)
Heating	Primary System	3,39	3,42	0,68	0,62
	Secondary System	3,95	4,15	1,41	0,74
Cooling	Primary System	0,30	0,11	0,02	0,04
Domestic Hot Water	Primary System	0,00	0,00	0,00	0,04
	Secondary System	0,00	0,00	0,00	0,05
Electricity		0,00	0,00	0,00	0,00
Total		7,63	7,69	2,12	1,53
Agregated Results		Energy need (kWh/y)	Energy demand (KWh/y)	CO2 emissions (KgCO2/y)	Energy Cost (€/y)
Heating		17 559,99	18 139,03	5 019,59	3 252,07
Cooling		708,62	262,45	52,49	102,84
Domestic Hot Water		0,00	0,00	0,00	214,08
Electricity		0,00	0,00	0,00	0,00
Total		18 268,61	18 401,48	5 072,08	3 568,99

Figure 3. Set of relevant outputs from the calculations (building level)

2.2.2 Related tools

The most similar tools aimed at suggesting improvements in the Spanish context are CE3 and CEX. These pieces of software are officially recognised as implementing the Spanish National Energy Certification for already built buildings (Figure 4).

CALIFICACIÓN ENERGÉTICA OBTENIDA:



El técnico certificador abajo firmante certifica que ha realizado la calificación energética del edificio o de la parte que se certifica de acuerdo con el procedimiento establecido por la normativa vigente y que son ciertos los datos que figuran en el presente documento, y sus anexos:

Figure 4. Example national energy certificate

The legislation underlying this software forces the inclusion of a module aimed to allow users to consider potential improvements to the energy use of a building which has previously been certified with the same software. In particular, the improvements suggested by the software (with interaction of the technical person in charge) must allow the building to improve its energy certification by at least one class (from E to D, for instance).

CE3 and CEX are highly relevant examples because they are both recent (the use of such software has been mandatory since June the 30th, 2013) and because they are being applied all across the Spanish country. They have become the undisputable reference among the majority of the population regarding energy efficiency at building level (Figure 5).

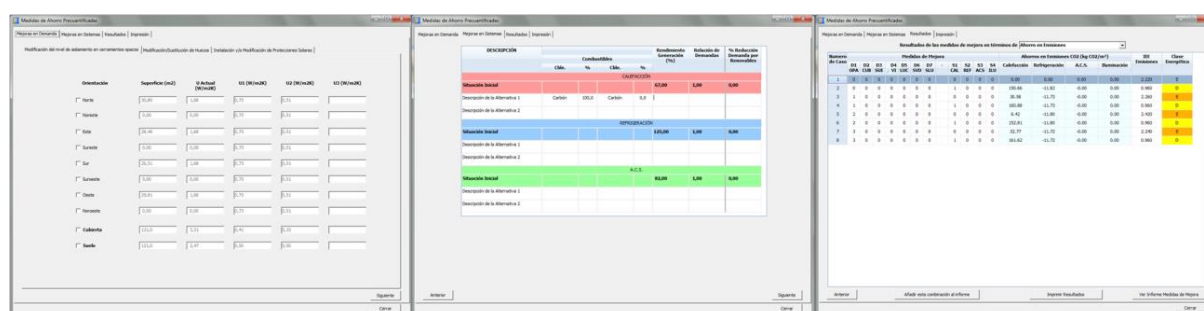


Figure 5. Screens of the improvement section for CE3 software

When dealing with the “improvement” section of the legal specification, both pieces of software take into consideration parameters influencing both the enclosure of the building and its equipment.

The user is asked to select among a list of pre-defined improvements or to define new ones (inside those categories), and the system provides a combination of improvements among the ones selected, with its corresponding result in terms of CO₂ emissions and Energy Certification (label). Then, the user selects among those combinations and adds them in his report which is the final output of the process (Figure 6).

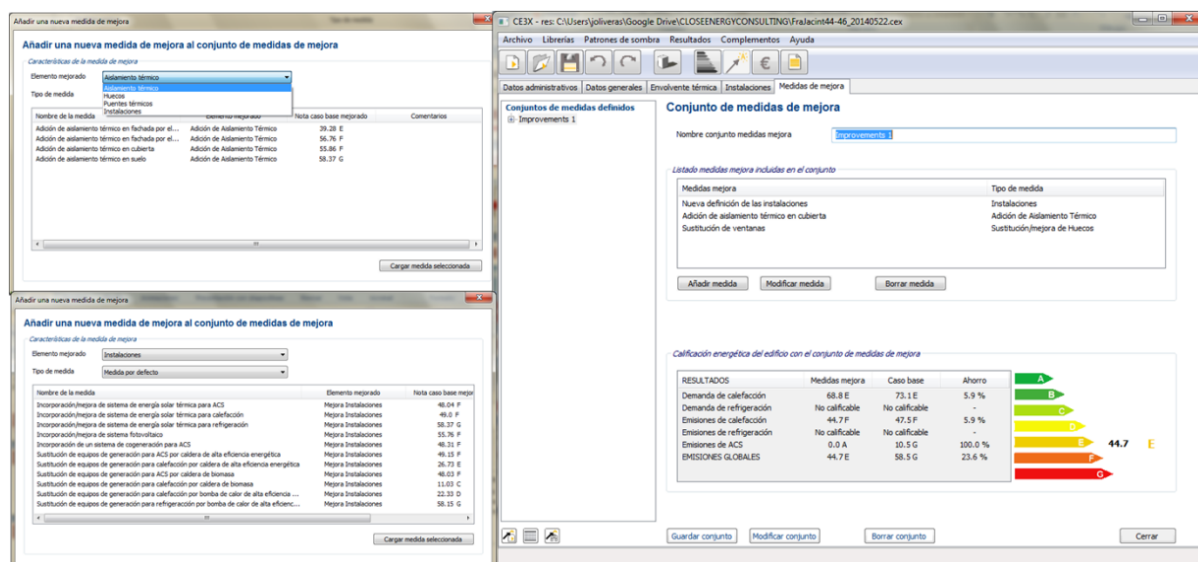


Figure 6. Screens of the improvement section for CEX software

The process described is meant to be addressed for a single building, but the “improvement” options could equally be used for one or more buildings at a time.

2.2.3 Context of use

During the second demonstration of the platform (Deliverable 8.3), users found that both the form and the workflow that the platform offered at that stage for making improvements were very useful. However, at this point all improvements had to be made using the URSOS tool described in Deliverable 5.1 *Building extraction and classification tools* and Deliverable 5.5 *Interoperable tools with SEIF*. To use this tool in this way requires that users fully understand many of the concepts and parameters appearing in the form, which are described in a form that only energy experts would fully understand. For instance, enclosure elements (facades, openings, roof) are described in terms of U values, alpha value, g-value, etc.

Since the target users of the tool for judging improvements are not energy experts – almost all of the users addressed during the demonstrations and dissemination events expressed their concern in these terms, and asked for help windows and reference values for each parameter – there was a need to create a new tool with a correspondingly simplified interface. The tool described in this section achieves this by providing a simple interface pointing to the most relevant actions that can improve the energy performance of a building.

As with the Newcastle tool, this tool for judging improvements shares the underlying calculation engine used by the URSOS tool that was used to establish the baseline measurements used in the Manresa case study. This allows the tool to take the detailed individual features of each house into account when considering the effects of proposed improvements, thus helping to

intelligently target refits at those houses which will most benefit from them.

2.2.4 Tool description

Finally, precisely which set of refits are offered by the improvement tool, and how the interface presents them to the users must be described. When the user selects the improvement tool from the “Plan” menu, the platform presents the form showed in Figure 7, in which the user can select among a pre-defined list of energy efficient improvements to be applied to the set of buildings included within a plan.

Figure 7. Improvement tool form

There are six possible energy efficient improvements, which entail upgrading the building systems and/or building enclosures, as follows:

- **Improving the building fabric.** These improvements entail upgrading the building enclosure parameters, specifically their U-value (affecting walls, roof and windows). With these upgraded U-values, the platform calculates (by means of applying the URSOS calculation engine) the reduced heating and cooling energy demand of the building. Based on these values, the platform calculates the CO₂ emissions and the energy demand of the buildings and of the urban area. The three options are:
 - **Window improvement.** This option simulates to change the windows of the buildings. In order to do so, the user has the possibility to choose among seven frame types and nine glass types. Then, the tool calculates the U-value of the new windows made by the combination of the chosen glass and frame, and assigns this upgraded U-value to all the windows of the buildings within the Plan.
 - **Façade isolation improvement.** This option simulates improving the insulation of the building fabric by adding new insulation material. When the user selects this option, the tool gives him the possibility to choose among four different types of insulation materials, with different thicknesses which can be applied either external or internally to the wall. Then, the tool calculates the upgraded U-value of the walls and assigns this value to the buildings.
 - **Roof isolation improvement.** It operates in a similar way to the façade isolation improvement.
- **Improvements to the systems within the building.** These types of improvements alter the efficiency with which the building can produce the heat and electricity needed to meet its demand. In turn this produces upgraded values for the energy demand and CO₂ emissions

(active measures). The upgraded CO₂ emissions are calculated considering the upgraded energy demand and the new energy carriers.

- **Domestic hot water improvement.** This option simulates the replacement of the systems providing DHW with more efficient ones. When this option is selected, the user has the possibility to choose among ten predefined boilers (System type). The tool indicates the energy carrier used by the selected boiler.
- **Heating system improvement.** It operates in a similar way, but it offers fifteen possible heating systems with their corresponding energy carriers and efficiencies.
- **Add renewable thermal energy supply.** The user will have the possibility to indicate the percentage of the energy needs which will be supplied by systems fed with renewal energy.

Each one of these improvements has been defined as tables and formulas linking the available options with the corresponding values to fill in the default form. An example of the list of options offered by the tool can be found in Figure 8 below. This figure shows the range of possible options given after selecting “Heating system improvement”. The tool presents these as a drop-down list, with the options for selection in the column Final_Energy_Generator.

Final_Energy_Generator	Space_Heating_Energy_Carrier	Space_Heating_System_Efficiency
Heating boiler standard combustion	Natural gas	0,9
Heating boiler low temperature combustion	Natural gas	0,9
Heating boiler condensation combustion	Natural gas	0,9
Heating boiler biomass	Biomass	0,85
Heating boiler electric	Electricity	0,99
Mixed boiler standard combustion	Natural gas	0,9
Mixed boiler low temperature combustion	Natural gas	0,9
Mixed boiler condensation combustion	Natural gas	0,85
Mixed boiler biomass	Biomass	0,9
Mixed boiler electric	Electricity	0,99
Electric system night tariff	Electricity	0,95
Other electric system	Electricity	0,95
Heating boiler standard combustion - Gasoil	Gasoil	0,9
Heat pump Split/Multisplit	Electricity	2,7
Heat pump air pipes	Electricity	2,7

Figure 8. Example of table linking improvement options with the corresponding values in the form

When selecting an option from this table, the user is principally allowed to both select the type of boiler that they wish to consider fitting to the property. The energy carrier is intrinsic to the choice of boiler and so cannot be changed, but the default values for the system efficiency can be altered by the user. Finally, the platform defines the system installed as the improvement as the primary heating system with an overall coverage of 100%. The coverage of the secondary heating system is therefore set to 0%.

The other improvement options have similar tables. When using the tool, the user can apply more than one improvement option. For each improvement option select the user has to specify their parameters. Once they are satisfied with the list of improvements to be applied for each project, they click to let the tool calculate their effects. After this, the energy simulation for the buildings is recalculated with the new configuration using the URSOS calculation engine. When

doing this the parameters fed into URSOS are altered in accordance with the set of selected improvements.

The tool automates the process of the building recalculation, so the user can create several projects and different improvements having the results in just a few steps. The ultimate output of using the tool is therefore a measure of energy use/CO₂ production for the proposed set of improvements.

These results can be compared to both the baseline scenario and to the identical results resulting from applying different sets of improvements in other projects. This is illustrated in Figure 9 below. In order to do this, the user moves onto using the MCDM tool for decision assessment between all the lists of projects.

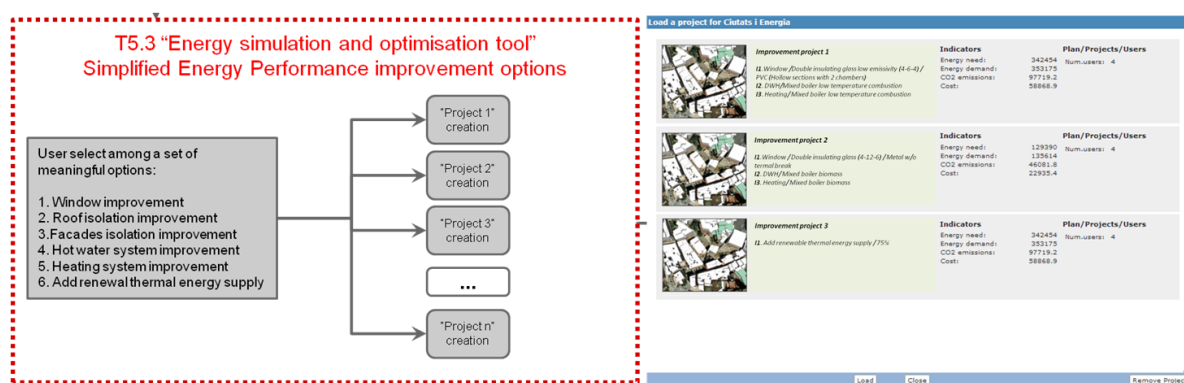


Figure 9. Final output of the Improvement tool. List of projects

2.3 The New Harbour Tool

2.3.1 Case study considerations

In contrast to the case studies in both Newcastle and Manresa, that of New Harbour in Copenhagen is focused on a greenfield planning situation. In this case, the improvement assessment tool focuses on considering interventions in terms of different ways that new areas of housing might be constructed rather than which refits should be applied to existing housing.

In order to develop an energy efficient urban district with reduced CO₂ emissions, usually several energy demand measures and energy supply options are analysed, so that the optimal combination of measures can be determined on the basis of energy saving and CO₂ reductions potentials and cost criteria.

The main objective of the Urban Energy Optimisation tool (UEO) is to determine the optimal combination of measures regarding sustainable energy supply and energy savings, with the lowest possible costs, in a greenfield planning situation.

The UEO-tool aims at identifying energy saving reduction potentials and the incremental cost for different energy saving measures and energy supply solutions for the North Harbour case study area².

The difference between the Urban Energy Planning tool (UEP) developed in Task 5.1 and the Urban Energy Optimization tool (UEO) developed in Task 5.3 is that UEP is used to plan the

² As a point of reference for the North Harbour case study area, it is assumed that the buildings are designed according to Danish minimum standards of 2010 and the future expectations to the National Building Codes.

urban area (e.g. determine energy intensities for buildings and energy supply options), whereas UEO is used to optimize the urban area by adding one or more initiatives/measures considering the energy reduction potentials and the related incremental cost in a given project. Once UEO has been applied in a project the user can move on to the next alternative project and add different initiatives/measures and calculate the reduction potentials and related incremental cost. Finally the indicators for different projects can be compared by using the MCDA tool.

2.3.2 Context of use

Despite the differences in context between greenfield and refurbishment, the overall context of use for this tool is very similar to that for the other two intervention assessment tools. The table below summarises this and notes the differences where they occur:

- A given area within North Harbour area has been selected and the corresponding tool described in Task 5.1 used to create a proposal for a baseline set of buildings that should be constructed there.
- The user selects this area as an appropriate area to consider the effect of construction buildings with different energy performance standards (e.g. level of insulation, U-value of windows). This represents a major area of divergence from the workflow seen with the Newcastle and Manresa tools – instead of selecting a set of discrete buildings to constitute the *plan*, the user instead selects a set of geographical areas with buildings with consistent intended energy performances.
- Having selected the area within the plan the user can create a project and use the tool described in Section 2.5.3 below in order to analyse the effects (e.g. energy saving reduction potentials and related cost) for implementing different initiatives/measures, which represent different sets of energy performance standards for the buildings and different energy supply options for the proposed area.
- The user can then look at the different levels of energy reduction potentials and costs resulting from the proposed initiatives/measures for the selected buildings and make the most cost effective choice. Ultimately, it will be possible for them to use the MCDA tool described in Chapter 3 of the current document to do this.

2.3.3 Tool description

On the energy demand side the UEO tool considers the following alternative building performance levels, which are based on different degrees of insulation:

- **Reference building.** Based on minimum requirements in the Danish national building code (2010). Insulation: 200 mm; window U-value: 2,0 W/m²K
- **Insulation 1.** Extra insulation of building envelope compared to reference building with 100 mm (300 mm total); window U-value: 1,5 W/m²K
- **Insulation 2.** Extra insulation of building envelope compared to reference building with 200 mm (400 mm total); window U-value: 1,2 W/m²K
- **Insulation 3.** Extra insulation of building envelope compared to reference building with 300 mm (500 mm total); window U-value: 1,2 W/m²K

The reference building is deliberately chosen with a relatively low degree of insulation, based on current minimum Danish energy performance standards (2010), in order to assure that the low hanging fruits with respect to energy savings through improved building insulation are included into the comparison between different measures.

In order to prioritize the most cost effective and environmentally sound solutions for the North

Harbour case study area, the effects of applying a series of sustainable energy supply measures are calculated as well.

Figure 10 below shows how different energy supply or demand measures in the North Harbour case study may contribute to the reduction in energy consumption as well as the costs associated with those measures (cost per kWh saved or cost per kWh of energy supplied).

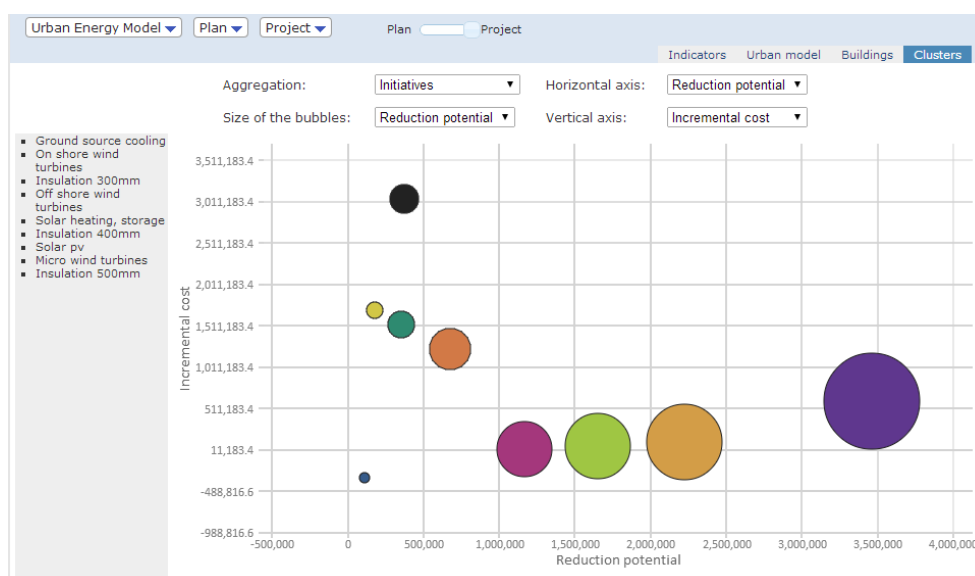


Figure 10. Comparison of fossil fuel reduction potential and reduction costs of a series of demand and supply options. Reduction potential and costs are accounted for per kWh/m² of gross floor area in buildings

The form in Figure 11 enables the stakeholders to select the most cost-effective measures to meet a desired level of reduction of energy consumption and CO₂ emissions. Since there are no details of the individual buildings considered, these figures are universally relevant for all of the buildings under consideration. Depending on the urban scale that the user wants to analyse, they can be applied to a single building, a cluster of buildings or the whole urban area.

"Ramboll tool": Edit initiative measures p578.kmz-283				
Initiatives		Reduction potential (kWh)	Incremental cost (€/kWh)	
<div>Add initiative</div>				
Initiative 1	<div>Insulation 300mm</div>	<div>101766.06</div>	<div>3670.92</div>	<div>X</div>
Initiative 2	<div>Insulation 400mm</div>	<div>41671.74</div>	<div>76341.54</div>	<div>X</div>
Initiative 3	<div>Insulation 500mm</div>	<div>22773.3</div>	<div>187828.74</div>	<div>X</div>

Figure 11. User interface where the user chooses different initiatives and the related "reduction potential" and "Incremental cost" for building(s)

On the basis of the default values provided for the North Harbour case study area calculated outside the platform a range of different scenarios can be developed, combining different energy supply and demand options.

In the example below (Figure 11) the user goes to the platform, loads a plan (baseline) and

creates a new project to analyse the effect of using different levels of insulation in the new buildings.

The calculation of “*Reduction potential*” and “*Incremental cost*” for the initiatives/measures is based on below default data table provided for the North Harbour case study (Figure 12).

Saving Initiatives	Saving [kWh/m ²]	[EUR/kWh/m ²]
Ground source cooling	1	-0,38
On Shore wind turbines	10,58	0,03
Insulation 300 mm	14,97	0,07
Off shore wind turbines	20,17	0,13
Solar heating, storage	31,35	0,73
Insulation 400 mm	6,13	1,50
Solar pv	3,18	1,86
Micro wind turbines	1,59	2,06
Insulation 500 mm	3,35	3,68

Figure 12. Default table for the North Harbour case study showing reduction potentials and related incremental costs for the initiatives considered on the energy demand and supply side

By adding the initiatives to one or several buildings in the project it is possible, as seen in Figure 13 below, to see the potential energy saving and the related incremental cost of the initiatives for the selected buildings:

Plan

Project

Plan

Project

Indicators

Urban model

Buildings

Clusters

Search

Clear

Insulation 300mm		Insulation 400mm		Insulation 500mm	
Reduction potential (kWh)	Incremental cost (€/kWh)	Reduction potential (kWh)	Incremental cost (€/kWh)	Reduction potential (kWh)	Incremental cost (€/kWh)
65538.66	2364.12	26837.14	49164.94	14666.3	120964.14
23907.09	862.38	9789.61	17934.31	5349.95	44125.11
9191.58	331.56	3763.82	6895.22	2056.9	16964.82
14984.97	540.54	6136.13	11241.23	3353.35	27657.63
27335.22	986.04	11193.38	20505.98	6117.1	50452.38
36511.83	1317.06	14951.07	27389.97	8170.65	67389.57
23966.97	864.54	9814.13	17979.23	5363.35	44235.63
247513.98	8928.36	101353.42	185676.82	55388.9	456834.42
12559.83	453.06	5143.07	9421.97	2810.65	23181.57
30374.13	1095.66	12437.77	22785.67	6797.15	56061.27
8173.62	294.84	3346.98	6131.58	1829.1	15085.98
75778.14	2733.48	31030.06	56846.26	16957.7	139863.06
19670.58	709.56	8054.82	14756.22	4401.9	36305.82
20763.39	748.98	8502.31	15576.01	4646.45	38322.81
15299.34	551.88	6264.86	11477.06	3423.7	28237.86
(770,251.41)	(27,784.62)	(315,406.89)	(577,817.19)	(172,367.55)	(1,421,646.39)

Figure 13. Urban model view for the North Harbour case study showing reduction potentials and related incremental costs for the three selected initiatives considered for selected buildings in the plan.

Based on the analysis conducted the energy planner can recommend the most cost effective insulation level.

2.4 The Newcastle Tool

2.4.1 Case study considerations

The pressing need for the consideration of the energy efficiency of existing housing stock can be seen from considering the situation within the United Kingdom. In the UK buildings contribute almost half of all CO₂ emissions with 26% of these emissions coming from approximately 26 million residential dwellings. Since, even before the current economic troubles across Europe, the building stock renewal rate in the UK was only 1-2 per cent³ it is clear that many of these existing buildings will still be present for the foreseeable future. Indeed it is expected that about 75% of the existing UK domestic stock will be still present in 2050 (Boardman 2007, Wright 2008).

In order to meet the UK's 80% CO₂ emissions reduction target it is thus a primary requirement that efficient methods for precisely identifying both those elements of the existing housing stock that are most need in improvement and how these might be improved are developed (Mhalas et al., 2012). While the need for such work is most pressing in the case of the UK, and especially so in light of the poor energy performance of the current UK housing stock (Boardman, 2007), similar circumstances pertain within other countries in the European Union.

The purpose of the corresponding tool developed in Task 5.1, and described in Deliverable 5.1, was to address the first part of this problem, namely that of providing a fast, efficient and cheap method for providing a baseline assessment of the energy efficiency of the existing housing stock. Having done this the next task is to focus on those houses most in need of improvement, i.e. those with bad existing energy efficiency, and to consider which of the many possible energy improvement interventions might be best suited to being applied to this housing.

When considering the refitting of existing homes, there are several viewpoints which must be considered and taken into account. More detailed considerations of these matters can be found in the relevant sections of Deliverable 2.1 *Report of the case studies and analysis* and Deliverable 6.1 *Stakeholder requirements analysis*.

In summary, while alternative use cases for this tool do exist, the main intended user of these tools is a social housing provider such as 'Your Homes Newcastle' which is involved in the UK case study. Such entities are responsible for owning and managing a collection of social houses on the behalf of local councils. In this case they either have an identified grant to spend on refitting some of their homes and are working out how it might be best targeted or are interested in developing a case to apply for money to do this. However when deciding on the best refit they must balance a considerable number of differing viewpoints:

- The installation cost of the refit, which will be borne by the social housing provider. For certain technologies and refits these costs can be mitigated by UK Government grants/subsidy schemes.
- The difference in the yearly heating/electricity bill for the property after the refit. These costs are typically borne by the occupiers of the properties in question who are often poor so must be kept low.
- The need to minimise the CO₂ emissions of the property in question.
- The need to minimise the net energy usage of the property in question.

³ See either of: <http://www.bis.gov.uk/assets/foresight/docs/energy/energy%20final/ravetz%20paper-section%205.pdf>; <http://www.eci.ox.ac.uk/research/energy/downloads/40house/40house.pdf>

While many of the refit options do contribute to each of these goals, they often do so to differing degrees. A principal requirement on the refit tool is therefore that it should provide sufficient information to allow the users to carefully balance these requirements against each other. It should also incorporate the various UK government subsidies of relevance such as the feed in tariffs for renewable electricity⁴ and the renewable heat incentive⁵. Finally there is the Green deal⁶ to consider. This is a funding arrangement involving installing the refits as a loan which is subsequently repaid over time through the tenants electricity bill.

2.4.2 Related tools

Various approaches to offering consideration of refit for houses have been investigated. One prominent European project in this area was TABULA⁷, which produced a publically available web based tool⁸. However, while the TABULA tool does permit the consideration of refit options, it works with both a fixed typology containing a few distinct, previously selected, dwelling types and a fixed set of options for which refits are undertaken.

Indeed TABULA does not even consider the specific physical dimensions of the dwellings concerned. Thus while it is suitable for considering the wide scale effects of refits, it provides much less flexibility than the tool developed within T5.3 in terms of considering both which refits best suit which specific dwellings and which combinations of them might work best. As the case study given in Section 3.4 of this document illustrates, these effects can have very substantial practical implications and should ideally be considered whenever it is practical to do so.

Another tool, with particular relevance to the Newcastle case, is the Carbon Mixer tool⁹. This tool was specifically designed to help consider such refits and features a dynamically updated supplier database containing information regarding both the efficiency and cost of potential refits. However, the tool is ill suited to considering the application of refits in medium or large scale programs. Rating and considering refits for, a house requires that one must not only provide a very detailed three dimensional model of that dwelling but also detailed information about its existing fabric. The requirement to input this amount of information before considering refits would, in practice, force the use of a typology based approach.

Indeed, similar considerations apply to any approach using a full scale energy model for establishing the characteristics of the dwellings under consideration. The reason that the tool presented in this document can exist, and provide a useful contribution for certain classes of refit schemes, is that it can build on the foundations offered by the tool in Deliverable 5.1. This tool permits the quick and cheap production of energy classifications for individual dwellings which are none the less valuable guides when considering refits. It thus allows refit schemes to reflect the individual characteristics of the houses considered.

2.4.3 Context of use

The basic use case for applying the intervention tool within the context of the Newcastle case study is as follows:

- The user has established an urban energy model containing a set of baseline figures derived from the tools presented for the Newcastle case study in Deliverable 5.1. They

⁴ <http://www.energysavingtrust.org.uk/Generating-energy/Getting-money-back/Feed-In-Tariffs-scheme-FITs>

⁵ <http://www.energysavingtrust.org.uk/Generating-energy/Getting-money-back/Renewable-Heat-Incentive-RHI>

⁶ <http://www.energysavingtrust.org.uk/Take-action/Find-a-grant/Green-Deal-and-ECO>

⁷ <http://www.building-typology.eu/#>

⁸ <http://webtool.building-typology.eu/webtool/tabula.html?c=all>

⁹ <http://www.bobbygilbert.co.uk/CarbonMixer.html>

have subsequently selected a discrete set of those buildings as comprising the *plan* within which they are working.

- For each building within the plan they have the subsequent option of using the intervention assessment tool to propose refits for it. For each such dwelling they select and click on, an interface is presented on which a set of refits are offered, some with user editable parameters. The user selects some of these.
- Having selected some of these, the user can then click a button to calculate the effects and costs of these refits.

The effects of each of these refits are then applied to the parameters of the dwelling being evaluated before the calculation engine developed as part of the Newcastle baseline energy modelling tools is applied. In this way the calculation of the effects of the refits considers not only the specific physical parameters of the dwelling but the combined effects of the improvements.¹⁰

The calculation of the cost of the refits also, where appropriate, uses parameters of the dwelling. For instance the cost of installing insulation scales with the wall area which would need insulation to be applied to it.

- The user can consider multiple refit options, before deciding which they wish to ‘commit’ to the model of the city. Chapter 2 above illustrates how this data can then be visualised and aggregated within the integrated platform.
- When they have committed the set of desired refits for each of the buildings that they have done, the results of each of these calculations are combined to produce an overall rating for the *project*.
- The user can create multiple different projects for the given plan, each containing different sets of proposed refits for the individual houses. These can later be compared using the MCDA tool in Chapter 3.

2.4.4 Tool description

The remaining questions relate to intervention assessment tool itself: what set of refits are offered and what data is shown to help the user decide which ones they wish to apply? Figures 14 and 15 below show the range of possible refits offered by the tool.

Fabric Improvements	Capital Improvements	Indicator Results	Financial Results
Add extra wall insulation	<input type="checkbox"/> External Insulation	<input type="checkbox"/> Internal Insulation	
Add extra loft insulation	<input type="checkbox"/>		
Insulate Floor	<input type="checkbox"/>		
Insulate Windows	<input type="checkbox"/>		
Water Cylinder Insulation	<input type="checkbox"/>		
Change Internal temperature	<input type="checkbox"/>	Select target temperature	21

Figure 14. Fabric refits

¹⁰ For instance the absolute gains from switching the type of boiler in a dwelling are much lower in a dwelling with high levels of insulation than an non-insulated one.

The screenshot shows the 'Capital Improvements' tab in the SEMANTCO tool. It contains a list of five improvement options, each with a checkbox. The 'Install Solar Thermal' option is checked, and its associated parameters are displayed: 'Orientation' is set to 'NORTH' and 'Overshading' is set to 'HEAVY'. The other options are unchecked.

Figure 15. Capital improvements

These figures show the two major categories of refit – fabric ones which involve improving the efficiency of the dwelling, principally by fitting more insulation, and capital ones which involve replacing the boiler used to generate heat. The following list briefly describes each improvement option offered; together with which parameters affect their installation costs and energy production:

- **Adding solar PV panels to the house.** This takes those chosen orientation for the panels as an input parameter but then estimates the size of panels to be produced from the previously specified roof area. This is then used to generate the installation cost and the annual amount of renewable electricity produced. A major consideration in this case is the effect of the UK government's renewable electricity generation tariff.
- **Adding solar thermal water heating to the house.** Here the orientation for the solar thermal and degree of over shading are both specified. The size of installation is then generated based on the roof area available and this is used to generate the installation cost and the quantity of renewably generated hot water.
- **Replacing the boiler currently in the property with a heat pump.** This has an option for air/ground heat sources, an electrical/gas driven pumping system and using either a radiator or under floor heating to distribute the heat. Each of these options affects both the efficiency and cost of the heat pump installation. The total size of the heat pump is assumed to match the heat requirements of the house.
- **Replacing the boiler currently within the property with a micro CHP boiler.** Here a single, fairly efficient type of CHP boiler is assumed to be used. The installation cost is therefore static. The raw energy use is identical to that of an efficient standard boiler but some additional renewable electricity is generated. This attracts UK government subsidies, thus affecting the financial calculation.
- **Replacing the boiler currently within the property with a combi boiler.** Again here a single type of highly efficient boiler is assumed with a fixed installation cost and efficiency.
- **Fitting additional insulation to the property.** Here all of adding internal/external wall insulation, filling in empty cavities in cavity walls, super-efficient windows, loft insulation, floor insulation and water cylinder insulation are permitted. The cost of installing the insulation depends on both the depth of insulation chosen and, for walls and roofs, the area of the property that must be insulated. This latter figure is taken directly from the baseline energy management calculations for that property.
- **A social intervention.** This option allows the consideration of the effect of changing the assumed internal temperature within the property. By default this is assumed to be 21 degrees. No cost is assigned to this intervention.

Once a refit has been selected and the potential parameters of it, such as the depth of insulation to be added, have been selected then both the effects of it on the energy efficiency of the house

and its installation cost must be calculated.

The remaining inputs required beyond those described in the list above are the raw cost data – for instance the cost per square meter of a chosen quantity of insulation, the cost of a given capacity of solar panel etc. Currently these costs are taken from approximate data gleaned from papers and public data sources.

In principle it would be better to use a dynamically updated set of costs with data taken direct from the suppliers. Indeed, the Carbon Mixer¹¹ tool incorporates such a database for fabric refits in the UK, and the SEIF –developed within WP4 of SEMANTCO– would be ideally suited to integrating such a database with the existing software. However, keeping such a database up to date requires an ongoing effort in terms of getting up to date information from suppliers and in hosting the database. Such data is thus not available in open source fashion and could not therefore be incorporated into the SEMANTCO prototype. This remains an avenue for potential future work.

Having calculated an approximate cost for the installation of the chosen improvement, the intervention assessment tool must then calculate the effects of the improvement on the day to day running cost of the flat. In order to do this the tool uses an updated version of the SAP calculation engine originally developed for the Newcastle case study within Task 5.1. This is based on the RDSAP specification within the SAP 2009 specification document¹² with certain simplifications to cater for the fact that the calculations use data from externally viewed dwellings rather than site visits.

For many of the improvements above, the SAP¹³ specification contains a detailed description of how the effect that that improvement will have on the energy production should be calculated. These specifications have been incorporated into the extended form of the SAP calculation engine within the 5.3 intervention assessment tool. In addition, certain improvements are incorporated directly by simply altering certain internal factors within the SAP calculation. For instance, the social intervention of altering the target internal room temperature is simply modelled by changing this parameter within the SAP calculation engine.

The ability to use an extended version of the calculation engine in this way offers several powerful abilities to the intervention assessment tool. The first is that the interactions between the individual features of each house and the improvements can be considered. The second is that the effects of combining multiple, simultaneous, improvements can be accurately calculated.

The final advantage to being able to use an extended version of the SAP calculation engine concerns the wide range of outputs that the tool can produce. In total, the intervention assessment tool produces the following primary indicators – both before and after the improvements:

- **SAP Rating.**
- **Annual net CO₂ production**
- **Annual net CO₂ production per square meter of floor space**
- **Annual total energy use**
- **Annual cost**

These indicators have been deemed fundamental as they represent the ones which are likely to be the legally mandated targets of any improvement scheme. While many improvements will

¹¹ <http://www.bobbygilbert.co.uk/CarbonMixer.html>

¹² <http://www.bre.co.uk/sap2009/page.jsp?id=1642>

¹³ <https://www.gov.uk/standard-assessment-procedure>

simultaneously target all of them, many will in fact produce varying effects. In particular electricity is currently much more expensive than gas so some electrically driven improvements can significantly reduce overall energy use but increase both the SAP rating and annual running costs. A screenshot of the interface used to show these is given in Figure 16 below.

The screenshot shows the 'Indicator Results' tab of the SEMANTCO interface. It includes buttons for 'Calculate Improvements' and 'Store Improvements'. Below these, a table titled 'Annual indicators' displays data for 'Baseline', 'With Improvements', and 'Difference' across four metrics: 'SAP Net CO₂ (Kg)', 'CO₂/m² (Kg/m²)', 'Cost', and 'Energy Use (kWh)'.

	SAP Net CO ₂ (Kg)	CO ₂ /m ² (Kg/m ²)	Cost	Energy Use (kWh)
Baseline	52.0 7781.0	56.0	1343.0	38134.0
With Improvements	50.0 5907.0	42.0	1409.0	11425.0
Difference	-2.0 1874.0	14.0	-66.0	26709.0

Figure 16. Indicator results

In addition to these basic indicators, more detailed financial considerations can be very important for deciding what refits are feasible for the social housing provider to undertake. The tool therefore provides extensive support for the consideration of financial indicators, including the following factors:

- The upfront installation cost for the combined refit. An estimate for this is calculated in the manner indicated above, but is left user editable so that the user can incorporate either additional sources of information or factors such as the discounts achievable when bulk refitting multiple houses in one area.
- The expected payment from the renewable heat incentive scheme¹⁴. This is a scheme produced by the UK Government in order to promote the installation of renewable heat production capacity within the UK. It pays a tariff for every kWh of renewable heat generated over 7 years. The level of this tariff varies according to the renewable heat technology involved but normally represents a substantial proportion of the upfront installation cost.
- The expected payment from the renewable electricity generation scheme¹⁵. This operates like the renewable heat generation scheme above but pays out over twenty years per kWh of electricity produced in a renewable manner. It offsets a large proportion of the installation cost for technologies such as solar PV and wind power.
- The net yearly difference in the annual fuel bill for the dwelling.
- An estimate for the annual inflation in energy prices over the following twenty years. This is a crucial factor in the calculation of lifetime cost/benefit of this sort of refit, but cannot be easily predicted. It is therefore left user editable to allow people to explore the effects of varying levels of predicted annual energy inflation on their financial planning.
- The net financial lifetime cost/benefit of installing the refits in question. In this case the expected improvement lifetime is taken as being twenty years. This includes both any tariff benefits and differences in the yearly bill. It thus represents the perspective of a potential long term owner occupier doing a refit of their property.

¹⁴<http://www.energysavingtrust.org.uk/Generating-energy/Getting-money-back/Renewable-Heat-Incentive-RHI>

¹⁵ <http://www.energysavingtrust.org.uk/Generating-energy/Getting-money-back/Feed-In-Tariffs-scheme-FITs>

- The net financial lifetime cost/benefit of installing the refits in question using green deal funding. The green deal¹⁶ is a recent UK Government scheme whereby the upfront cost of installing refits is given as a grant which is repaid over a course of time through the customer's annual heating/electricity bill. In order to be eligible for such a refit, the reduction in this bill must be greater than the annual repayment cost. Calculating the lifetime cost benefit of doing this gives a good estimate of whether this will be possible.
- Equivalent ROI (return on investment) and years to recoup original investment – these calculate how cost effective fitting the proposed refits is from a purely financial perspective. Especially if a healthy level of energy price inflation is assumed, and government tariffs included, this is often positive.

The combination of these two sets of indicators together with the ability to use the specific parameters of the houses to guide them allows people to gain a good idea of how effective specific combinations of refits might be. All of these features can be seen in the interface in Figure 17 below.

Fabric Improvements	Capital Improvements	Indicator Results	Financial Results
Up Front Install Cost	<input type="text" value="0.0"/>		
Heating Tariff (7 years)		Electricity Tariff (20 years)	<input type="text" value="0.0"/>
Net lifetime Cost/Benefit	<input type="text" value="0.0"/>		
Estimated yearly energy price inflation	<input type="text" value="5"/>		
Equivalent ROI	<input type="text" value="-100.0"/>	Years to recoup original investment	<input type="text" value="1.0"/>
Green Deal Interest Rate	<input type="text" value="7.0"/>	Green Deal Lifetime	<input type="text" value="20.0"/>
			Net lifetime Cost/Benefit, Green Deal <input type="text" value="0.0"/>

All monetary values in UK pounds.

The Government Generation tariffs (above) rise in line with RPI (assumed to average 4 per cent over the time concerned). Potential interest from investing savings not considered.

CO₂ and energy cost assumptions based on those within the SAP specifications.

The ROI calculation assumes a total write off of the initial capital after twenty years.

Currently the costs (per kWh) are taken as 0.0529 for off peak electricity, 0.1146 for always on electricity and 0.031 for gas.

CO₂ 'costs' (in Kg/kWh) are taken as 0.517 for electricity and 0.198 for gas. These values may well be subject to change as the power grid decarbonises.

When considering generated electricity half is assumed to go back to the grid, half directly used and the full value used for calculating the CO₂ reduction.

When considering heat pumps, micro CHP etc the installation is presumed adequate to cover the entire houses heating needs.

Figure 17. Considering the financial data

The final place in which these results can be seen is within the overall SEMANCO platform, when clicking on a house to which improvements have previously been attached shows a summary set of the results of those improvements. A screen shot of this is seen in Figure 18 below where the blue house is the one selected.

¹⁶ <http://www.energysavingtrust.org.uk/Take-action/Find-a-grant/Green-Deal-and-ECO>

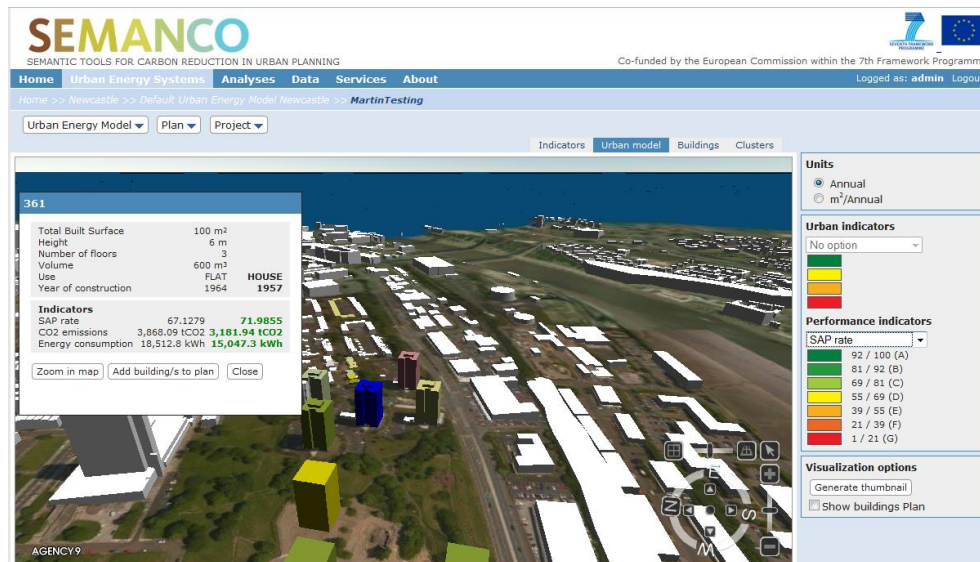


Figure 18. Illustration of improvement results within Integrated platform

In addition to this text based visualisation, the integrated platform offers features allowing for the graphical comparison of the energy efficiency of buildings before and after the application of refits. A full description of this lies outside the scope of the current deliverable but can be found in Deliverables 5.4 and 5.6 which describe the overall operation of the integrated platform.

3 THE DECISION SUPPORT TOOL

3.1 Introduction

The tools seen in Chapter 3 allow for the creation of plans concerning the optimisation of certain elements of the energy efficiency of an urban environment. In addition they allow for the calculation of detailed information regarding certain quantitative elements for each plan.

For a given set of improvements, multiple different criteria are affected, some positively, some negatively. Since there is typically no single dominating criteria a multi criteria decision support tool was developed. In the terms of Chapter 2 above, this tool allows for different *projects* within a given *plan* to be compared using multiple simultaneous criteria and so assists the user in selecting the best one.

In order to do this the tool uses a multi criteria decision analysis (MCDA) algorithm. The resultant tool is described in the following section. The interface and context in which this tool is invoked are described in Chapter 2.

3.2 Multi Criteria Decision Analysis

When analysing an urban system, a socio-economic and biophysical complex system, its relevant aspects cannot be captured using a single perspective (Funtowicz et al., 1999; O'Connor et al., 1996). Urban systems present multiple identities at multiple scales, which are subject to non-equivalent descriptions. An architect would describe a building in terms of volumes, shapes, materials and orientation. A sociologist would look at the people living in the building, and describe it according to its demographic, cultural and socio-economic characteristics.

Different people with different backgrounds would focus on different aspects of the building according to what they consider relevant for the analysis. Due to the principles of incommensurability, those relevant aspects are rendered irreducible to each other by “the absence of a common unit of measurement across plural values” (Martinez-Alier et al., 1998, p. 280). According to these arguments, in Deliverable 2.3 *Impact verification*, the SEMANTCO project defined a set of multidimensional indicators in order to assess the energy performance of urban plans and projects. These can be used to compare different projects against both the existing baseline energy use and other proposed plans.

Contrary to other evaluation methods (e.g. cost benefit analysis, life cycle assessment, ecological footprint, carbon footprint), multicriteria methods enable the user to perform comparisons in a manner which combines the consideration of all relevant factors, including both none directly comparable quantitative aspects and even qualitative ones.

In order to carry out the evaluation and comparison of alternatives, a multi-criteria problem can be structured as shown in Table 1, which is called the impact matrix. The matrix contains n possible actions A_j ($j = 1, 2, \dots, n$) and m performance indicators g_i ($i = 1, 2, \dots, m$). Indicators are at least partially contradictory, that means that one alternative can be the best under one indicator, but not necessarily under the rest of them.

Table 1. Multi-criteria impact matrix

Criteria	Alternatives			
	A_1	A_2	-	A_n
g_1	$g_1(A_1)$	$g_1(A_2)$	-	$g_1(A_n)$
g_2	$g_2(A_1)$	-	-	-
-	-	-	-	-
-	-	-	-	-
g_m	$g_m(A_1)$	$g_m(A_2)$	-	$g_m(A_n)$

Once all alternatives have been evaluated under the different indicators (i.e. the construction of the impact matrix), an aggregation procedure (i.e. algorithm) is applied and this generates a ranking of alternatives. There are numerous methods for solving multi-criteria problems (Figueira et al., 2005; Ananda & Heralth, 2009), each with its own advantages and disadvantages, depending on the application context (Montis et al., 2004). For applications in the public policy domain, it is advisable that the multicriteria method used should fulfil the following conditions (Janssen & Munda, 1999; Munda, 2004; Munda 2005):

- Be as simple as possible to guarantee transparency among the counterparts;
- Be either partially or fully non-compensatory¹⁷;
- Use weights as importance coefficients;¹⁸
- Consider the intensity of preferences.¹⁹

There are no multicriteria methods which simultaneously fulfil all of these requisites. Some methods transform the criterion scores to a single unit of measure in order to perform the comparison of alternatives (e.g. Multi-attribute Value Function). These methods, for instance, use weights as trade-off or substitution rates between criteria and they are completely compensatory. These features represent significant drawbacks in the current context which are also shared by all methods based on linear aggregation procedures (e.g. weighted sum).

Within SEMANTCO the decision was made to use the outranking method developed in Munda (2005): the C-K-Y-L method²⁰. This method was chosen as it fulfils most of the prerequisites for a multicriteria model to be used in the public policy domain outlined above. In summary, the benefits of this method include that its rationale is quite intuitive and easy to explain, that it is non compensatory¹⁶ and finally that the weights assigned to criteria are importance coefficients making their use intuitive for the target non expert users of the tool.

¹⁷ In a generic MCDA method, a very good performance in some criteria can offset bad performances in other criteria. This is undesirable in the current context and non-compensatory methods don't allow this.

¹⁸ On the one hand, weights as importance coefficients reflect the relative importance of one criterion in relation to the others. On the other hand, weights as trade-off reflect the substitution rate among criteria.

¹⁹ The intensity of preference involves the comparison of preference differences. For example, let w , x y and z denote levels of some attribute X . We might then compare one's degree of preference for x over w with one's degree of preference for z over y . This quaternary relation is denoted by $>^*$. Thus, $wx >^* yz$ implies the difference in preference going from w to x is greater than the difference in preference in going from y to z (Farquhar and Keller, 1989, pp. 205)

²⁰ Theoretical details of this algorithm can be found in Appendix A.

3.3 The MCDA tool

As mentioned in D2.2 *Strategies and Indicators for Monitoring CO₂ Emissions* and D2.3 *Impact Verification*, energy efficient urban planning is a multidimensional issue, in which energy performance is represented by some specific indicators (e.g. energy demand or energy consumption) within a set of multidimensional indicators. Therefore, it is not enough to look for the building and urban plans that yield the best results in respect to a single parameter such as energy performance. For example, a plan that performs well in terms of energy efficiency may incur sufficiently high costs to be undesirable overall.

Instead multiple parameters must be simultaneously considered. The purpose of the MCDA tool which has been implemented in the SEMANTCO platform is to support users in making such decisions by enabling the comparison of multiple differing plans for a given urban area under a multidimensional set of indicators.

The overall structure in which the multi criteria decision analysis tool operates was described in Chapter 2. Briefly, before using the tool, a user has selected an area of the city and designated this as comprising a specific *plan*. Within each plan there are then a set of *projects*, each of which corresponds to a proposed set of refits applied to the area of the city model within the chosen plan.

After loading a plan, the user can compare the different projects created within that plan. In order to do so, the user selects *compare* in the drop-down menu of plans (Figure 2).



Figure 2. Screenshot of the integrated platform. Drop-down menu to select to compare different projects within a plan

The platform then shows the option to perform a *New Analysis*. After selecting whether to perform a new analysis or to load a previous analysis, the platform presents the projects created within the plan and the raw indicator scores for each project are displayed. As well as any proposed refit projects, the baseline situation is also shown and considered within the MCDA analysis. The projects and indicator scores are structured in what is called the impact matrix (highlighted by the red box in Figure 20). The multicriteria comparison is based upon the information contained in the impact matrix and on two parameters to be defined by the user: the weight and preference thresholds (highlighted by the blue box in Figure 20).

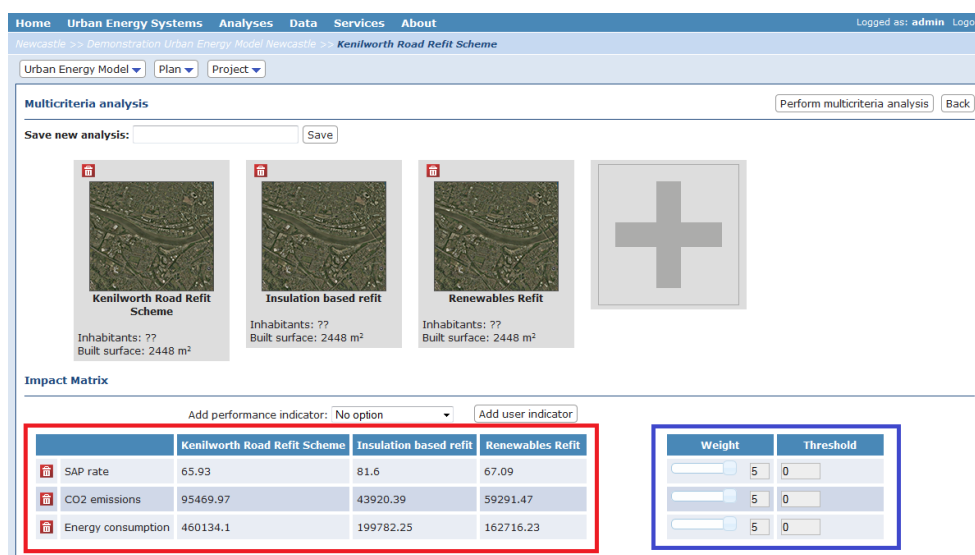


Figure 3. Screenshot of the integrated platform. Alternative projects and the impact matrix with the indicators scores

The MCDA method chosen within SEMANTO is not compensatory, so the weights seen attached to each criteria in Figure 20 should be considered as denoting *importance coefficients*. That is, the weight assigned to a given indicator denotes its absolute importance when considering the desirability of a given project. This value is independent of both the range of possible values that the indicator might take and of the choice of units used to measure the indicators. In this method weights do not refer to trade-off or substitution rates among indicators. Rather they refer to the importance spontaneously assigned by a user who has been asked to do so while knowing neither the scale nor the units used for the evaluation. In a voting process, for instance, these weights would refer to the amount of voters in favour of a project, who would be represented by the indicator.

The value of weights range from 0 to 5. Once every indicator has been assigned a weight, the algorithm evaluates the relative size of these weights and transforms them into a set of normalised weightings. Each of the normalised weights falls within the range of 0 and 1, and the sum of all of the normalised weights is 1. Any indicator given a zero weight is considered to have no importance and is not further considered in the multicriteria comparison.

The preference threshold is the minimum difference between the performances of two projects under one indicator that makes one option preferable to the other. For instance, if the cost of two projects is 5.500€ and 7.000€ respectively, and the preference threshold is equal to 1.000€, then the first project is preferable. If the preference threshold is equal to 2.000€, both projects would be considered as equal with respect to the cost indicator.

The user also has the possibility to manually add a new indicator. This feature can be used in cases in which the user has additional information that is not provided by the platform. For instance, one can add an indicator of costs or social perception.

As well as indicating the name, and values of this new indicator the user must indicate if this indicator is one where high values are good – one that should be maximised – or one where low values are good, i.e. one that should be minimised. The default option within the platform is minimisation, but the user has the possibility to check *Max* to indicate that the indicator should instead be maximized. Cost, for instance, is an indicator to minimise, while social acceptance can be defined as an indicator to maximise (e.g. degree of acceptance). Consider, for instance, that the user defines a scale from 0 to 10 to assess social acceptance, in which 0 means no acceptance and 10 means complete acceptance. In this type of indicator and similar ones using scales of categories (e.g. from very bad to very good) the threshold has to be defined equal to 1

(Figure 21).

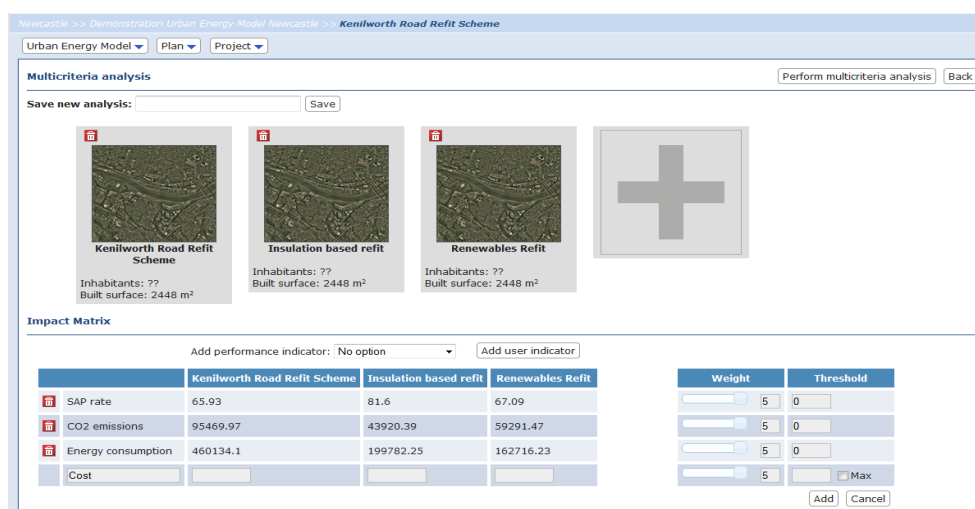


Figure 4. Screenshot of the integrated platform. Addition of a new indicator

3.4 Worked Examples of the MCDA tool in action

In order to illustrate the use of the MCDA tool within the SEMANTO integrated platform, consider a case where a *plan* has been created to refit the set of buildings around the Kenilworth road area in Newcastle and two *projects* proposing different ways of doing this have been created. One of these projects proposes to refit the houses with extensive fabric insulation, the other with renewable energy and electricity generation options. The baseline option, denoted by the plan's name of Kenilworth road refit scheme, is also considered in the analysis. The basic results from these can be seen in Figure 22.

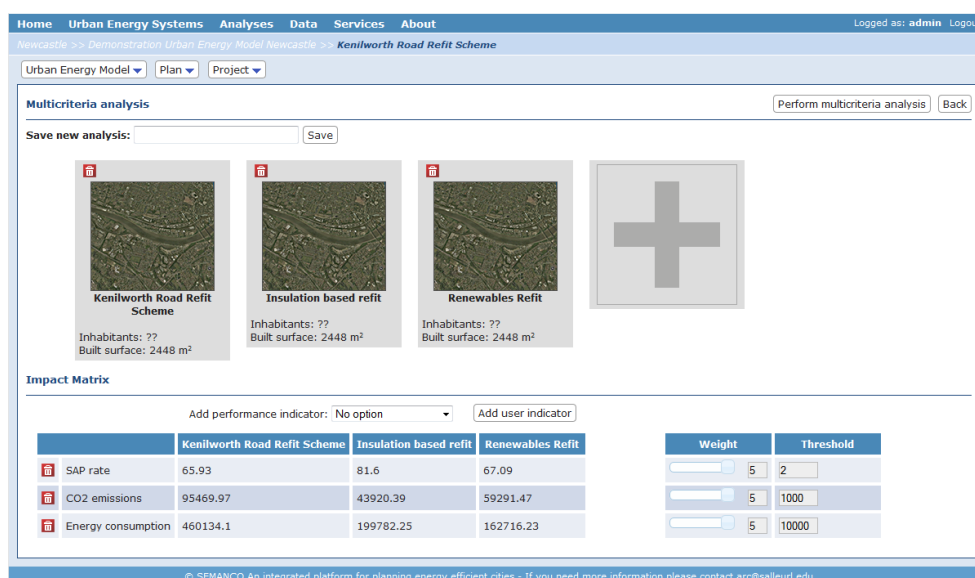


Figure 5. Screen before running the MCDA tool

As well as seeing the raw result figures from these projects, the proper use of the thresholds can be seen in this screen shot – the SAP rate runs on a scale from 0 to 100 and so has a threshold of 2 assigned to it which the 6 figure results for energy consumption have the much higher threshold of 10.000.

As can be seen from examining the concrete figures, both of these proposed refit projects notably

increase certain aspects of the energy efficiency of the area of housing. The areas in which they have most impact however differ somewhat.

The insulation based refit produces a considerable increase in the average SAP rate of the houses, and has the lowest assigned CO₂ emissions of the options under consideration. However the renewable energies refit has the lowest overall energy consumption.²¹

This presents a dilemma to the user, of the sort which the MCDA tool is designed to support their resolution of. In setting the appropriate weights and thresholds for each indicator, they will drive the tool to produce an appropriate ranking of the possible options. Figure 23 illustrates the results if the weights are all set to an equal value – namely that the insulation based refit is the most attractive. This would be expected as it does much better in terms of one indicator (SAP) and is roughly equal to the renewable energies refit in the other two.

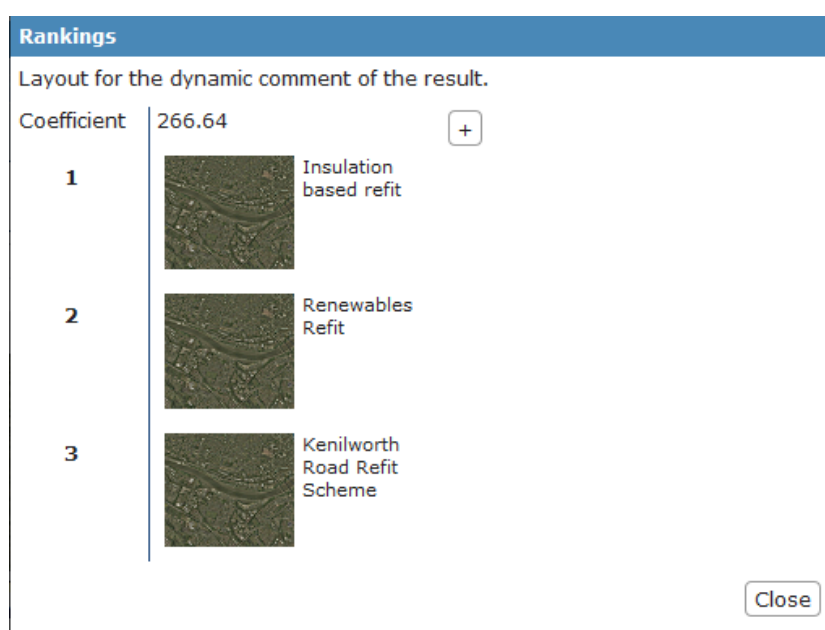


Figure 6. Ranking with equal weights.

However, should the user choose to focus principally on energy consumption, and so set the weight of that to 5 and that of SAP and CO₂ to one, then the rankings of the two projects reverse, as seen in Figure 24.

²¹ The size of this variation is principally due to the renewable refit moving the heating of the houses to be powered by electricity instead of gas. The SAP calculations assume electricity to be much more expensive, and produce more CO₂, per kWh of energy, than gas.

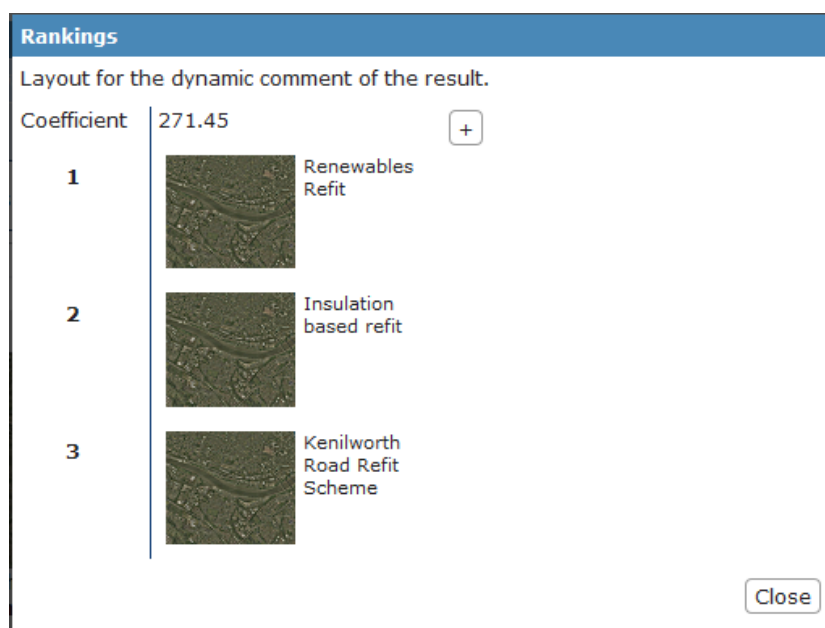


Figure 7. Ranking, weights heavily favouring energy consumption

This example, while simpler than many that would be met in reality, illustrates the basic principle of the MCDA tool. Namely, it transforms the problem of choosing between different proposed projects into one of selecting which criteria the user is most interested in. This is a much easier task overall so the tool provides a very useful contribution to the overall functionality of the SEMANCO integrated platform.

One final feature of the MCDA tool is of relevance – the chosen MCDA method does not only calculate a single ranking between the alternatives. Instead it calculates all possible pairwise rankings and then chooses the ‘most probable’ of these to show to the user²². In some cases the choice of ranking to present to the user is clear cut.

In many cases however, there are multiple different rankings which the method judges to be probable enough to worthy of consideration. In this case the MCDA tool within the SEMANCO integrated platform is capable of displaying all such rankings. The + button visible on Figures 23 and 24 displays these when clicked. An example of this, from the case with equal weights above, can be seen in Figure 25.

²² See Appendix A for a detailed discussion of the mathematical algorithm underlying the MCDA method used within the tool, including the definition of ‘most probably’ within this context.

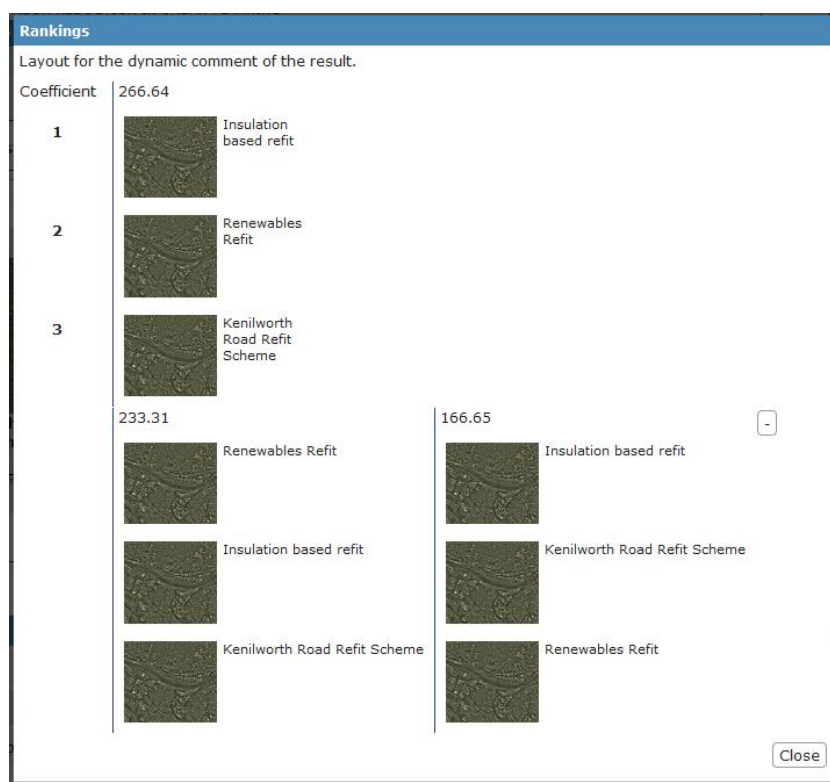


Figure 8. Multiple probable rankings being displayed

In this case the top ranking is the most probable (valid) one, with a net coefficient of 266.64. The second of the rankings is however only slightly less valid with a coefficient of 233.31. Since these two rankings simply swap over the ranking of the two projects, based on just those rankings the tool only offers a small indication of preferring the Insulation based refit over the renewable energies one.

The third ranking however, while less probable overall with a coefficient of 166.65, put the renewable energies based refit at the bottom of the rankings. The total of all of the three rankings therefore strongly indicates that, with the weights selected by the user, the insulation based refit should be preferred.

The ability to illustrate all of these sets of comparisons is a powerful feature of the approach to MCDA chosen within SEMANCO. It is likely to be of particular utility in situations where there are a large number of refit projects to choose between and the user wishes to select just a few of them to focus on.

The final feature offered by the MCDA tool within SEMANCO is the ability to add user defined criteria to the evaluation. To see the potentially crucial utility of this, consider the effects of considering cost as a criterion within the case study of Chapter 2.

As described in Chapter 3, and especially pages 20/1 of that Chapter, the combination of the complexity of Government tariffs can make the consideration of costs very complex when the production of renewable energy/heat is involved. In consequence we shall here only consider projects containing fabric refits here.

The two refit projects compared here are the fabric refit project originally outlined in Chapter 2 where the additional insulation is added to every single house within the refit area and a 'targeted' refit project where the insulation is only added where it considerably increases the SAP value of that property. The values for the comparison between these two projects can be seen in Figure 26 below.

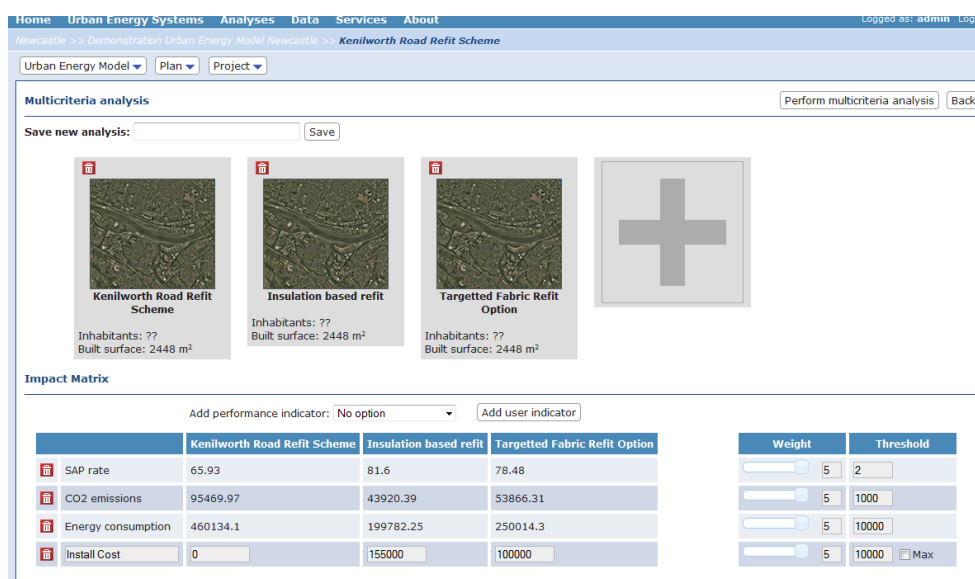


Figure 9. Comparison with user supplied install costs added

As would be expected, the scheme which insulates every house has a higher net improvement in terms of SAP, CO₂ and energy consumption but also a considerably higher overall cost than the targeted scheme. This follows even more strongly in the case of the baseline scenario.

The results of using the MCDA tool can then provide very valuable information to the user when considering which project they prefer. This is another example illustrating the utility of showing multiple rankings. If all of the weights are set equal to each other, then Figure 27 shows the results. While this represents a preference for the total refit scheme, the targeted refit is also shown as worthy of consideration.

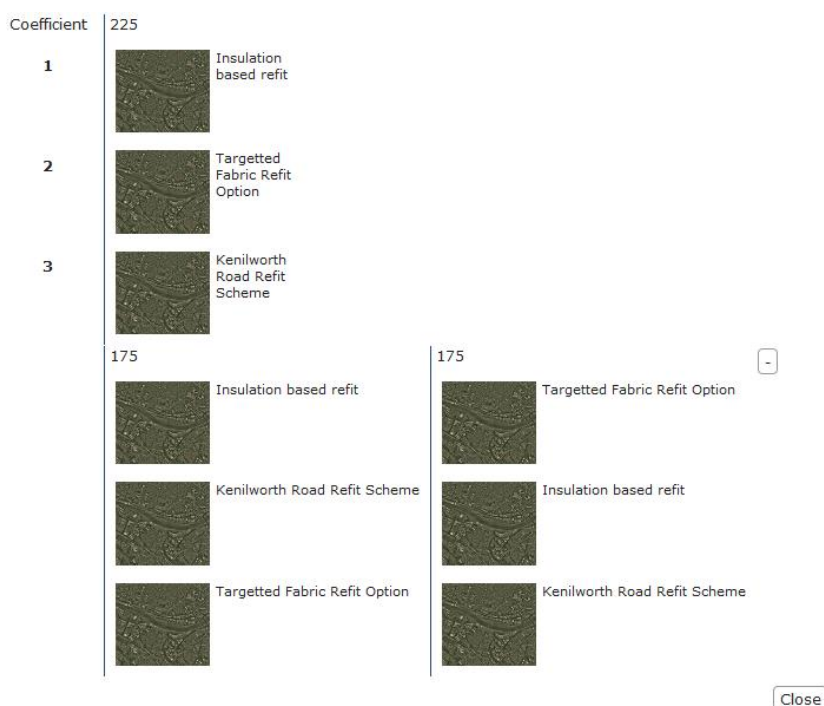


Figure 10. Cost added as a user defined criteria, equal weights

If cost is given a weight of 5 and the other criteria a weight of 1 then the algorithm returns a notable preference for the baseline result, which obviously costs nothing. Indeed when considering cost the baseline scenario should probably not be considered.

If the baseline option is removed then giving cost a weight of 5 and the other criteria 1 each produces a fairly strong recommendation for the targeted refit. Putting the other criteria to have a weight of 2 each produces a very weak recommendation for the full scale fabric refit. Here both rankings are always shown as possible but the strength of the recommendation is given by the difference in the size of the coefficients attached to each of these.

This sort of scenario demonstrates how the extreme flexibility of the MCDA tool implemented within SEMANCO allows users to intelligently explore the range of options open to them, and so provides a very effective tool to support their making decisions as to which refit projects should be selected.

4 CONCLUSIONS

4.1 Contribution to overall picture

This deliverable has described the software tools which have been developed within the process of work on Task 5.3 *Energy simulation and optimisation tool*. These have included:

- Intervention assessment tools for each of the three case study areas within the SEMANCO project have been developed. These build on the basis of the baseline measurement methodologies presented in Deliverable 5.1 in order to allow for the quantitative evaluation of given interventions, such as refitting houses.

Each of the tools allow for the consideration of both the individual characteristics of the areas being refitted when considering the impact of these proposed refits.

- An MCDA tool allowing for the consideration of both the quantitative output arising from the intervention assessment tools and non-directly comparable quantitative factors when comparing multiple different sets of potential refits.

The combination of these tools fulfils the goals set out in the description of work for Task 5.3. All of these tools have been fully specified, developed and implemented within the current version of the SEMANCO platform. In combination they comprise a highly effective framework for developing plans for refitting urban areas and for comparing the potential effects of those urban plans.

4.2 Impact on other WPs and Tasks

The software implementation work within Task 5.3 has had the principal impact of developing components of software for use within the SEMANCO integrated platform and of completing the integration of the outputs of Task 5.1 *Building stock energy modelling tool*. This has therefore all contributed towards Task 5.4 *Prototype of the integrated platform* and Task 5.6 *Integrated platform*. In turn it has then contributed to all demonstration and user testing activities within the SEMANCO project.

Besides their use within the integrated platform no further tasks rely on these outputs.

4.3 Contribution to demonstration

The outputs of Task 5.3 form crucial elements of the SEMANCO platform which will be used in the demonstrations carried out during the project.

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6 APPENDIX A: UNDERLYING THEORY OF MULTI CRITERIA DECISION ANALYSIS

A.1 The Outranking Method

When considering the requirements for developing an MCDA tool for use within the SEMANTCO integrated platform, the decision was made to use an outranking method. Basically, an outranking method performs a pair wise comparison: two alternatives are compared criterion by criterion and a binary relation of preference between both alternatives is defined. This comparison is performed for each of the $N \cdot (N-1)$ possible pairs of alternatives, where N is the number of alternatives.

The result of this step is an outranking matrix of $n \times n$ alternatives. The elements e_{jk} of the matrix indicate the degree of preference of the alternative i over alternative j , for all possible pairs of alternatives. Each outranking method uses slightly different methods to construct the outranking matrix.

Having calculated the outranking matrix, the next step is the calculation of the ranking of alternatives. This is done with the information contained in the outranking matrix. Again, each outranking method uses its own procedure to obtain the ranking of alternatives. Outranking methods can be partially or non-compensatory, use weights as important coefficients and consider intensity of preference thanks to the use of indifference and preference thresholds²³.

The multicriteria method chosen for the SEMANTCO project has been developed in Munda (2005); the C-K-Y-L method. This method begins the procedure by constructing the outranking matrix in a way that each element e_{jk} of the matrix is equal to the sum of the weights of criteria under which alternative j is better than alternative k , plus half of the weight of the criterion under which alternatives j and k are indifferent. In this case, indifference and preference are modelled using only a preference threshold²⁴.

The procedure continues with the calculation of a coefficient Φ for all $N!$ possible rankings. The ranking that maximises Φ is the most probable ranking.

The coefficient Φ indicates how many criteria are “in favour” of each ranking, taking in consideration the criterion weights. For instance, if one has the following ranking: $A > B > C$ ($>$ means “at least as good as”); the coefficient Φ is calculated by summing up the weights of the criteria under which $A > B$, $A > C$ and $B > C$. A higher Φ coefficient would mean a larger number of votes supporting that ranking.

Several factors influence the rankings of alternatives: the quality of the information and data, the chosen criteria or indicators, the aggregation method the criterion weights and/or the preference

²³ The indifference threshold is the maximum difference between the criterion scores of two alternatives that makes no difference between them (under that criterion). The preference threshold is the minimum difference between the performances of two alternatives in one criterion that makes one option preferable to another

²⁴ If the difference between the criterion scores of two alternatives is higher than the preference threshold, then one alternative is better than the other. If the difference is lower than the preference threshold, then both alternatives are indifferent.

thresholds. As the evaluation through the Semanco platform will be open to the general public and decision makers, it will be possible to carry out a quality control in both (i) the definition of the problem; (ii) the information used in the assessment and (iii) the calculation of criterion scores.

A.2 Worked Example

The following Table 1 shows an example of a multicriteria impact matrix, which contains the evaluation of 3 alternatives (A, B and C) under 3 indicators (x , y and z). The table also contains information about the weight of each indicator – in this case each one is assigned 33% –, the preference threshold and whether the criterion is for maximizing or minimizing.

Table 1. Multicriteria impact matrix

	Weight	Pref. Threshold	Max (1) / Min (0)	Alternative A	Alternative B	Alternative C
Criterion x	0.33	1	1	3	2	1
Criterion y	0.33	1	1	1	2	3
Criterion z	0.33	40	0	100	150	120

First, the C-K-Y-L algorithm performs a pair wise comparison of alternatives. When comparing two alternatives under one indicator, the algorithm calculates the difference between the indicator scores of both alternatives and compares this difference to the preference threshold. If the difference is higher than the preference threshold, the weight of the indicator is allocated to the better alternative between the two being compared. If the difference is lower than the preference threshold, then half of the weight of the indicator is allocated to each alternative. The process is repeated for each pair of alternatives and under all the set of indicators. The result is the outranking matrix presented in Table 2.

Table 2. Outranking matrix

	Alternative A	Alternative B	Alternative C
Alternative A	0.00	0.66	0.50
Alternative B	0.33	0.00	0.50
Alternative C	0.50	0.50	0.00

When comparing alternative A with alternative B, the former is better under indicators x and z . As a result, the element e_{12} (row 1 and column 2) is equal to the sum of the weights of indicators x and z . When comparing alternative A and alternative C, they are indifferent under indicator z ; the difference between their scores (20) is lower than the preference threshold (40). In this case the half of the weight (16,7%) is allocated to each indicator. As each alternative is better under one of the remaining indicators, the elements e_{13} and e_{31} take the value of 0,5.

Once the outranking matrix is obtained, the algorithm produces all the possible permutations of alternatives (i.e. rankings) and calculates the coefficient Φ for each of them. Table 3 present the 6 ranking with the corresponding Φ coefficients.

Table 3.

<i>Ranking</i>	<i>First</i>	<i>Second</i>	<i>Third</i>	Φ
1	Alternative A	Alternative B	Alternative C	1.66
2	Alternative A	Alternative C	Alternative B	1.66
3	Alternative C	Alternative A	Alternative B	1.66
4	Alternative B	Alternative A	Alternative C	1.33
5	Alternative B	Alternative C	Alternative A	1.33
6	Alternative C	Alternative B	Alternative A	1.33

Let's consider the following ranking:

- $A > B > C$

Its Φ coefficient is calculated by summing up the coefficient of the outranking matrix according to the relations between the alternatives indicated in the ranking. In this case we have the following relations:

- $A > B = 0,66$
- $A > C = 0,5$
- $B > C = 0,5$

Which yields the total of 1,66.

It is important to note that the algorithm does not produce a definitive ranking of alternatives. Instead it provides a set of rankings which each have their corresponding Φ coefficients attached, with each coefficient indicating the support given by the set of indicators. In this example, one could say that alternative A performs better than alternative C, and alternative C performs better than alternative B (based on the 3 rankings with the highest Φ coefficients).