*Eighth International IBPSA Conference*
**Eindhoven, Netherlands**
**August 11-14, 2003**

# A DECISION-MAKING TOOL TO SUPPORT INTEGRATION OF SUSTAINABLE TECHNOLOGIES IN REFURBISHMENT PROJECTS

Kari Alanne[1], Krzysztof Klobut[1]
[1] VTT Building and Transport, Espoo, Finland

## ABSTRACT

The aim of the European SSHORT (Sustainable Social Housing Refurbishment Technologies) project is to increase and promote rational and efficient use of energy in the retrofitting of social housing buildings. In this scope, one step was to develop a specific multi-criteria decision-making tool to support decision-makers in choosing the most adequate energy technological solutions for refurbishment in Europe. The tool (System Selection Tool) is based on a method for multi-criteria evaluation of combinatorial systems. The tool aims at an energy system as a combination of technical solutions. Different possible technical solutions are positioned in an output and compared with existing configuration of the project according to a multi-criteria profile. This paper will present the methodology, the structure, the assessment and setting preference methods included in the tool.

## CONTEXT AND OBJECTIVES

Rational and efficient end-use of energy in the built environment will be a key-contribution to reduction of $CO_2$ emissions. European Union has an aim to save 30% of energy currently consumed in built environment by 2010 and 50% in the longer term.

Considerable part of total stock of social housing buildings in Europe is now more than 25 years old. Many refurbishment works are performed nowadays throughout Europe in the social housing sector in order to:

- make buildings respectful of new standards and regulations (about electricity, water,...)
- reduce running costs (mainly by reducing energy and water consumption),
- increase inhabitants' comfort (essentially thermal, acoustic and visual comfort),
- increase building intrinsic value.

The SSHORT project, partly funded by the European Commission in the frame of the 5$^{th}$ RTD program, aims at validating the use of some sustainable energy technologies in the refurbishment of social housing.

The project is composed of several subtasks as follows:

- expectancies of social housing inhabitants, owners, and building professionals (WP1)
- development of a decision making tool for refurbishment (WP2)
- adaptation of simulation tools to evaluate the technical and economical interest of different technologies in standard case of social housing in participant countries (WP3)
- preliminary studies of selected technologies on demonstration operations in Finland, France and Italy (WP4)
- preparation of measurement procedures (WP5) which will be conducted on demonstration operations
- refurbishment and measurement campaigns on demonstration buildings (WP6)
- exploitation of demonstration results and spreading of project’s results (WP7)

Adoption of new technologies is linked with reasonable decisions. Thus, decision support is needed to encourage the decision-makers to commit themselves to sustainable development. The lack of a simple, comprehensive tool for decision-making of non-professional persons (building administrators, real estate owners etc.) has been identified and a need of such a tool has been recognized.

The following chapters will present an outline of a new tool. Firstly, some of the most important, existing tools are presented for building analysis and decision support. Secondly, a basic methodology of the new tool is described as well as its user-interface. Finally, some advantages and disadvantages of the new decision-supporting methodology are remarked and subjects for future research are suggested.

## EXISTING TOOLS FOR BUILDING ANALYSIS AND DECISION SUPPORT

### Analysis tools

Analysis tools could be a common name for tools that are used to produce data concerning existing or prospective buildings through numerical modelling, simulation of behaviour of a real building or based on operational experiences. In the case of building analysis, they can be roughly divided into *simulation tools* and *expert systems*. Output of these tools is essential for comparison of different alternatives in decision-making and selection of the best option. The data from analysis tools serves as an "input" for the actual decision-making tools. A few important tools for building analysis are presented in this chapter.

WinEtana is a simple simulation tool for energy consumption calculations. Information about building type, geometry and location (weather file) are needed as a source data as well as some specification concerning heating (room temperature, heating period etc.). The information is then used to calculate energy consumption and costs. This program contains a lot of default data (database) and it can also be regarded as an easy-to-use expert system (Kosonen et al., 1997).

TRNSYS - A Transient System Simulation Program is a comprehensive and sophisticated approach to building simulation. It is based on modular structure with dynamic models of single building components and is not applicable to simple simulations. It is quite difficult to use and interpretation of the results requires a lot of expertise. The assortment of variables is large, from the indoor conditions (temperature, humidity etc.) to energy consumption.

In the context of SSHORT project CA-SIS and PAPTER have been mentioned as tools for analyzing different systems based on TRNSYS-simulations. Other simulation tools applicable as data sources for the decision-making are CLIM 2000, ESP, Suncode, DOE-2, Passport and Summer.

A tool presented in reference (Marir et al., 1995) is an expert system based on practical experiences, aimed for managers of refurbishment projects to estimate costs. A new method called *Case Based Refurbishment* (CBR) makes it possible to utilize experiments and thus it is believed to give more human way of thinking to the evaluation of the benefits and drawbacks of a project. It also is believed to improve the reliability of the evaluations.

EPIQR, for apartment buildings, (Flourentzou et al., 2000) and TOBUS, for office buildings, (Flourentzou et al., 2002) softwares include a new methodology and a multimedia tool for architects and engineers that can help them in evaluations of existing buildings and different retrofit scenarios in the preliminary stages of a project. They are very versatile tools for processing and visualization of the information that can be gained from a building. These software do not decide for the user, but give guidelines to educated decision. This is why they can be regarded as analysis tools rather than decision-making tools.

### Decision-making Tools

Decision-making tools (or decision support systems) can be defined as tools, which help decision-maker to make decisions (or even propose a decision for the user) on the basis of data about the alternatives to be selected (Leitch et al., 1992). There are a number of decision-supporting tools mentioned in the literature, but three multi-criteria tools have been considered as the most suitable for building energy decisions.

HIPRE and PRIME are both developed in the Helsinki University of Technology. The main advantage of these tools is their ability to handle a set of conflicting criteria in a structured, illustrative way. PRIME's additional advantage is its possibility to handle information in intervals instead of single numbers. This makes it easier to consider inaccurate information, which is quite common in case of building energy choices. Both tools require from the user a high level of expertise concerning operational research (Gustafsson et al., 2001).

MCDM23 is like a "specialized version" of HIPRE or PRIME. It has been designed especially for the designers of building energy systems. Methodology behind the user interface is simpler and less structured, but instead, the tool includes some additional elements like a set of default criteria and a Life Cycle Calculator (Tanimoto et al., 2001).

None of these tools, however, has a capability to find automatically an "optimal path" from the large amount of single options, even though e.g. PRIME takes into account an ideology of system configuration (collection of an entire system from single components).

### Combined Analysis and Decision-making Tools

Relevant information is a prerequisite for effectual decision-making, which in building cases often is achievable only by simulation or through experience. In combined *analysis* and *decision-making* tools this requirement has been taken into account in some simplified way.

BDA (Building Design Advisor) is applicable to the needs of many interest groups, especially building designers, for research, development and education. Firstly, the user must create alternative(s) by means of a model consisting of contextual parameters (factors inaffectable by a designer, e.g. climate) and design parameters (building geometry etc.). Then, the program executes a simple simulation to find out the behaviour of the building. The most important benefit of this software is its ability to handle and visualize information achieved by the simulation. The program is not designed for multi-criteria evaluation, although comparison of different alternatives on the basis of different attributes has been made easy (Papamichael, 1999).

Energy 10 is rather a simulation tool than combined analysis and decision-making tool. It can be classified under this category because of possibility to compare one case with a pre-defined reference case. Energy 10 has been developed for the needs of building designers and provides light simulation on the basis of number of default database information. From this point of view, it is like a "plentiful" version of WinEtana. Taking into account the interest group, Energy 10 is mentioned to require "two days of training", but it is obviously too difficult to use for laymen.

## INTRODUCTION OF THE NEW TOOL

### General

Decisions are mainly made by a team consisting of a design group (an architect, HVAC engineer, electrical engineer etc.), a building owner (client) and a contractor. The design parameters, space arrangements and technological solutions as well as refurbishment or retrofit options are selected by the design team, in a close co-operation with the building owner. The design companies may also have their own strategies towards sustainability of the energy system, which is one of their strategic decisions. The importance of design team is strongly emphasized by literature concerning building energy choices (Huovila et al., 1999).

The decision-making is based on needs and requirements of occupants (and building owner). Designer has responsibility to follow the orders and directions of authorities in order to ensure compatibility with regulations and laws. Experienced designer can also bring into consideration some factors beyond the outlook of ordinary, unskilled building owner. As a conclusion, decisions are made in a close co-operation between building project participants. The decision-making process, particularly during the early stages of design, can be seen as an iterative and cyclical process, such as illustrated in Figure 1.

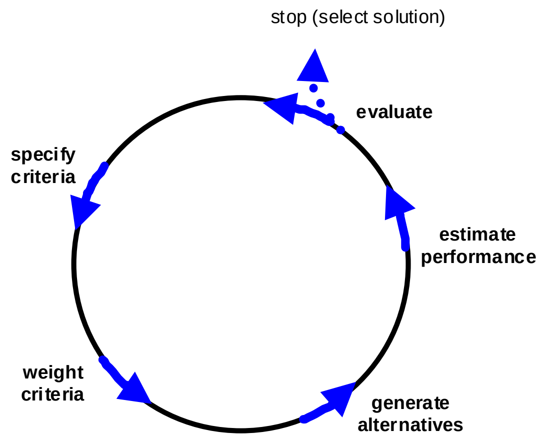


*Figure 1: An iterative, cyclical design process (Tanimoto et al., 2001)*

The tool presented in this paper is called System Selection Tool (SST). It is destined to be used in the cyclical design process to find the most feasible options for the refurbishment. Typically, the designers produce two or more design scenarios in preparation for a critique of the design group (Tanimoto et al., 2001). This moment is favourable to apply the new tool to automatically assess a mass of each design alternative by studying the effect of variations of single options. An easy-to-use tool has been the aim since the beginning of development of SST. It is designed also for persons who do not have deep understanding of mathematics behind decision-making and modelling (such as building owners). On the other hand, operational speed of the program has been set as a design criterion of the tool. Therefore the use of simulation models has been excluded. Because of simplicity, the structure of the tool is also quite straightforward.

In this chapter, the most important elements of the SST are concerned, which have been developed in the SSHORT-project in co-operation with project participants.

### Specifying the criteria

The dictionary definition of the term "criteria" is "standards of judgement or rules to test acceptability". In the literature concerning multi-criteria decision-making, this term, however, seems to indicate attributes. Attributes are defined as characteristic of the options being evaluated, which is measurable against some objective or subjective yardstick (Andresen et al., 1998).

The number and nature of the criteria will vary from one case to another. The set of attributes for a case will be defined in a co-operation of a design group. Thus the team's priorities reflect those of the client, the ultimate arbiter of criteria (i.e. building owner in the case concerned in this study). Usually, this can be achieved through sufficient number of meetings, maybe using some additional tools, e.g. QFD (Quality Function Deployment) method (Tanimoto et al., 2001, Huovila et al., 1999).

The criteria may be either quantitative, such as annual energy use, or qualitative, such as aesthetics. Usually, a tree-structured model is used, in which the starting points are general, strategic objectives (main-criteria, e.g. minimization of life-cycle costs, maximization of functionality), then narrowing the view into more specific levels (one or more levels of sub-criteria), until a reasonable target is reached. This means a level that can be defined by means of numerical or otherwise unambiguous factors (Tanimoto et al., 2001). This idea is illustrated in the Figure 2. (Tanimoto et al., 2001) recommends that the number of main-criteria should not exceed 8 and number of sub-criteria should not be more than 8 under each main-criterion. This is obviously in order to achieve simplicity, clarity and avoid overlapping evaluations.

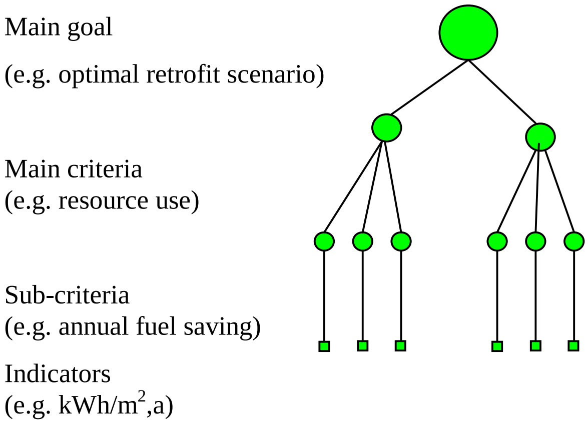


*Figure 2: A tree-structured criteria model (Tanimoto et al., 2001)*

In order to retain simple programmatic structure of the System Selection Tool, only a few the most important criteria are included for the user to choose from. The justification for the most important criteria arises from the objectives of the SSHORT project. Many refurbishment works in today's Europe in the social housing sector aim at:

- making buildings respectful of new standards and regulations
- reducing operating costs
- increasing inhabitants' comfort
- increasing building intrinsic value.

A framework of the issues that should be considered in building design and operation, is presented in Hakkinen et al., 2002 in the form of sustainability indicators. From among them, minimization of costs, maximization of functionality (including human comfort and technological feasibility in the form of reliability and controllability as sub-criteria) and minimization of environmental problems have been seen as the most important strategic objectives (main criteria) for this project. This set of criteria has been verified by the project participants in numerous meetings and on the basis of country-specific material.

## Weighting the criteria

The need for quantifying importance of different criteria with respect to each other arises from the nature of multi-criteria problems. For example, in the context of SSHORT-project a question arises: what if human requirements do not agree with energy saving options? One, widespread way to handle this problem is to assign criteria weights to indicate their relative importance. Vice versa, the criteria weights are indicators of the influence of individual criteria on the decision (Andresen et al., 1998). A number of methods exist for assigning the weight factors based on Multi Attribute Value Theory and The Analytical Hierarchy Process (Mustajoki et al., 1999).

In the context of SST Tool weighting is based on so called "Grading Method", which works with the weight factors directly and is simple to use. The criteria weights are determined on a 10-grade scale. The most important criterion receives a grade of 10 and all the other criteria are compared to it. For example**,** if a criterion is judged to be somewhat less important than the most important one, it receives a grade of 7 (see Table 1).

*Table 1: Eliciting the weights in the System Selection Tool using the Grading Method.*

| Grade | Relative importance compared with the most important criterion |
|---|---|
| 10 | Equal importance |
| 9 | |
| 8 | |
| 7 | Somewhat less important |
| 6 | |
| 5 | |
| 4 | |
| 3 | Significantly less important |
| 2 | |
| 1 | |
| 0 | Not important at all |

In a group decision case the weights of an *individual team member* are given as "votes" on 10 grade scale. This approach also provides a possibility to assign different importance to the opinion voted by each team member. Finally, the weight profile, indicating preference of the *whole group*, is a *weighted average* of the weights given by individual team members.

The following example illustrates this case (see Table 2). Team consists of two decision-makers (voter 1 and voter 2). The preferences of voter 1 are considered to be "the most important" (grade 10) and the preferences of voter 2 "significantly less important" (grade 3). If the voter 1 regards criterion 1 as "the most important" (grade 10) criterion and voter 2 regards them as "significantly less important" (grade 3), then the weighted average of these grades is 8 (= 0.77x10 + 0.23x3). Note that the weighted average will be rounded to the nearest integer.

*Table 2: Eliciting the weights in a Group Decision case*

| Voter | Importance of the voter | Normalized importance | Criterion 1 | Criterion 2 |
|---|---|---|---|---|
| 1 | 10 | 0.77 | 10 | 7 |
| 2 | 3 | 0.23 | 3 | 7 |
| | | Average | 8 | 7 |

After the weight elicitation process, the *set of weights* is fed into the System Selection Tool to calculate the optimal solution.

## Generating the alternatives

The responsibility of generating the alternatives lies with the design team. Then designers typically create as a "craft work" a number of scenarios, from among which the team makes a final choice (Tanimoto et al., 2001).

The method implemented in the System Selection Tool, gives a possibility to consider a large amount of alternatives instead of a few "craft-made" scenarios. Then the best one can be selected using multi-perspective, multi-criteria analysis. If all the options are mutually independent, a linear multi objective integer model (MOILP) can be used. Otherwise a model will be non-linear and more difficult to solve.

In the System Selection Tool this problem has been approached simply by formulating all workable combinations and then by calculating the total "value" for each combination. It has been noticed that this kind of approach works smoothly for up to 15,000 combinations. This is, by far greater number of scenarios than can be analysed in traditional, "craft-made" way.

The approach is based on a "hierarchical pool model". In this model a combination is considered as a set of sequential choices, each of them made among a "pool" including all the same type of options. Thus only one option among one single pool can be selected. There is an "ancestor" option on top of the hierarchy, which is independent on selection of any other choice. Beginning from the "ancestor" option, the other options have a "mother-child"- relations on the basis of their mutual dependencies. In the computer program, "pools" have been regarded as vectors and compatibility between different options is defined in so called compatibility matrix. Using this method, the compatibility of different options can be taken into account (Alanne et al., 2000).

In the SST, some key technical options have been included on the basis of discussions between the project participants and on the basis of country-specific material. User is able to limit the number of options by checking the options that he wants to be included in the analysis.

## Estimating the performance

Term utility is often used to describe the opposite of costs. To be able to estimate the utility achieved by selecting an option, performance prediction is required on the basis of some kind of case analysis. The performance prediction may be based on computer simulations, databases, rules of thumb, experience or expert judgement. The required level of detail depends on the available time, resources and accuracy demand. Typically, the performance score is based on consensus in the design team, usually achieved through voting and consulting external experts (Tanimoto et al., 2001).

If some automation could be employed to predict performance, new faster and simpler, though more inaccurate, methods for decision-making would become possible. In the case of large amount of technological options, automated performance prediction is practically necessary. It is quite obvious, that the data must be in a very simple form and definable for a single option as easily as possible. For example, in a case of 15.000 different combinations, dynamic simulations of large systems can be excluded. In practice, this means that the individual options must be assessable by means of score numbers. The score numbers, however, may be dependent on the presence of other options in a combination, if a non-linear approach is used.

Using this approach, reliability of dynamic simulations concerning entire systems is poor but indicative results are possible and, in this case, some amount of quality is substituted by a huge amount of quantity. However, in some conditions, this approach may provide results that otherwise would evade decision-maker's notice.

In the System Selection Tool, the performance prediction has been carried out by means of an expert database containing estimated score numbers being equivalent to each technological option and each criterion. The databases are constructed on the basis of experience, rules of thumb and opinions of experts. The score values are based on a value function methodology for quantitative criteria and verbal judgement for qualitative criteria (Tanimoto et al., 2001 for further information). In the System Selection Tool, the score numbers vary from 1 (the worst option) to 10 (the best option). A sample of System Selection Tool database is shown in Table 3.

*Table 3: A sample of database for the System Selection Tool.*

| ID | Technological Option | * |
|---|---|---|
| 1 | Electricity System: Network | **10** |
| 2 | Electricity System: Photovoltaics | **1** |
| 3 | Heating System: Oil Heating | **5** |
| 4 | Heating System: Electric Heating | **8** |
| 5 | Heating System: District Heating | **5** |
| 6 | Heating System: Heat Pump | **4** |
| 7 | Secondary Heating System: Fireplace | **10** |
| 8 | Secondary Heating System: Solar Collectors | **1** |
| 9 | Cooling System: No cooling | **10** |
| 10 | Cooling System: Heat Pump | **1** |
| 11 | Cooling System: Evaporative Cooling | **5** |
| 12 | Heat Distribution: Radiators | **10** |
| 13 | Heat Distribution: Convectors | **9** |
| 14 | Heat Distribution: Air | **5** |
| 15 | Heat Distribution: Floor | **1** |
| 16 | Heat Distribution: Ceiling | **3** |
| 17 | Ventilation: Natural | **10** |
| 18 | Ventilation: Extract Air Fans | **8** |
| 19 | Ventilation: Supply and Extract Air Fans | **4** |
| 20 | Ventilation: Supply and Extract Air Fans + HR | **1** |
| 21 | Lighting Control: Manual | **10** |
| 22 | Lighting Control: Presence control | **1** |
| 23 | Heating Control: Basic | **10** |
| 24 | Heating Control: Optimized | **1** |
| 25 | Ventilation Control: Manual | **10** |
| 26 | Ventilation Control: Time-based control | **5** |
| 27 | Ventilation Control: CO2-control | **1** |
| 28 | Fault Detection: No | **10** |
| 29 | Fault Detection: Yes | **1** |

*Score number for investment costs

## Evaluating the scenarios and making recommendations

The database is utilised for calculation of the commensurate value for each possible combination. Let us assume options 1...*i*...*n* and evaluation criteria 1...*j*...*m*. For each option, the score numbers are aggregated into one score number describing *utility of an option*. The *simple additive weighting model* is used for option *i* based on the criteria weights:

$$S_i = \sum_{j=1}^{m} w_j s_j$$

where:

- $S_i$ is the total utility achieved by selecting option *i*,
- $m$ is the number of criteria,
- $w_j$ is the normalised weight of the criterion *j*, and
- $s_j$ is the score for the criterion.

The value for *an entire combination* can then be calculated by summing up the utilities of single options recommended into this combination. The best combination will have the greatest value.

In the System Selection Tool, the existing configuration (before retrofit) is first defined and its performance is predicted. The total value (utility) of the existing configuration gets the index number 100. Then, the possible new scenarios are formulated and their performances predicted. The total values of the other scenarios are proportioned with respect to the total value of existing configuration by an index number and a comparison can be made. Finally, the decision is made whether the retrofit brings additional value or not. On the basis of the comparison, the 5 best (most added value) scenarios also are presented as a recommendation, using both text and graphical form.

It should be emphasized that the weight factors and performance prediction cause some uncertainty in the results. In order to take this into account, sensitivity analysis or the use of ranges instead of exact weight and score values like has been done in (Gustafsson et al., 2001) could be implemented in future version of the tool. Thinking about the decision-making, the calculated results should not be given more than an indicative status. The final decision should still be an outcome of human reasoning.

# CONCLUSION AND PERSPECTIVES

Adoption of new technologies is linked with reasonable decisions. Thus, decision support is needed to encourage the decision-makers to commit themselves to sustainable development. The lack of a simple but comprehensive tool for decision-making by non-professional persons (building administrators, real estate owners etc.) has led to development of a new decision-supporting tool.

In the European SSHORT project, a specific multi-criteria decision-making tool, called System Selection Tool, has been developed in order to support decision-makers in choosing the most adequate energy technological solutions for refurbishment in Europe. Typically, the designers produce two or more design alternatives in the early phase of a design process. This moment is favourable to apply the new tool to automatically assess a mass of design scenarios by studying the effect of variations of single options. User friendliness and operational speed of the program have been targets while developing the tool. Therefore the use of simulation models has been excluded. Because of simplicity, the structure of the tool is also quite straightforward.

This paper briefly presents the methodology, structure, the assessment and setting preference methods behind the new tool.

In the future, additional studies are needed in order to obtain reliable information about both the performance of buildings in different operational environments and the experience on the application of a method in this context. Especially, the subjective nature of qualification criteria should be better taken into account. The user-interface, data structures and software of the decision-making tool certainly need further improvement. At this phase of development, we recommend that the tool should be used as an expert decision-supporting service rather than as a standalone computational tool.

## ACKNOWLEDGEMENTS

The SSHORT project, notably results and work presented in this paper, is partly funded by the European Commission in the frame of the 5th RTD program.

Electricite de France (EDF) from France, Center for Renewable Energy Sources (CRES) from Greece and Solar Convert from Italy collaborated with VTT on the development of the SST tool.

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