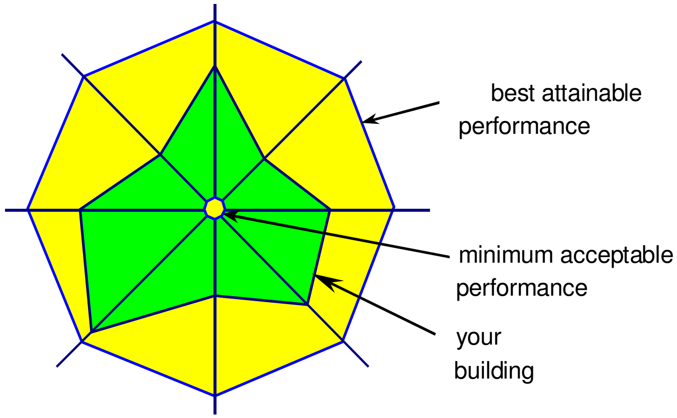
Multi-Criteria Decision-Making

MCDM-23

A Method for specifying and prioritising criteria and goals in design



February 25, 2002

International Energy Agency - Solar Heating and Cooling Programme
Task 23
Optimization of Solar Energy Use in Large Buildings
Subtask C
Tools for Trade-Off Analysis

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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Foreword

The International Energy Agency Solar Heating and Cooling Task 23, *Optimization of Solar Energy Use in Large Buildings*, is developing guidelines that will assist a design team through the process of designing solar low energy buildings. Subtask C of Task 23 is concerned with *Tools for Trade-Off Analysis*. A *Multi-Criteria Decision-Making Method*, *MCDM-23,* and an associated computer program have been developed by the Subtask to aid a design team at critical points in the design process.

Basically, there are two situations where *MCDM-23* should be used:

- In the process of designing a building:
  - when selecting and prioritizing among design criteria,
  - when evaluating alternative design solutions.
- In a design competition:
  - when developing the program,
  - when selecting the best design from among several submissions.

The *MCDM-23* is a formalized step-by-step procedure to aid in such decision-making processes, while the computer program automates many of the tasks involved in using the method and produces worksheets, bar charts, and star diagrams.

Contents

Introduction

The background for this booklet is the assumption that the success of low energy and ”green” buildings relies on the assessment and integration of all the different design objectives or *criteria*. These criteria are often quite complicated to deal with and may be conflicting. The different design issues and the many different available “green” and low energy technologies call for different areas of expertise to be involved in the design. This makes it difficult to evaluate the overall “goodness” of a proposed design solution, and the communication between design professionals and the client becomes complicated. The goal of the *MCDM-23* method is to produce a means for the design team and client to be able to better understand and handle holistic green building design. The *MCDM-23* method suggests that a structured approach for evaluating design alternatives based on *scoring* and *weighting* techniques might be effective.

A similar situation arises in programming and judging a design competition. The client or jury needs to decide what criteria that the design schemes should be judged against, and they also need to have a way of measuring the overall goodness of each design scheme. The judges in the jury must often consider many different criteria in the process of selecting the winning scheme.

These two situations have much in common:

- There are many criteria to be considered, all important but not necessarily all equal. The criteria will change from one project to another.
- Some method of comparing design alternatives must be devised.
- The results must be aggregated in a way that will allow the design team or the judges to see the big picture.

Both situations could benefit by using an organised approach. It should be noted that the method primarily is a means to organize the multi criteria design work and to learn and understand about what is important – not to produce the "right answer".

This booklet mainly describes the *MCDM-23* method itself. It also introduces the *MCDM-23* software that automates and facilitates use of the method. These tools do not reduce the building design process to a prescriptive procedure. Rather, they provide a framework within which to carry out the several tasks inherent in a partly qualitative discussion- and decision-making process.

The following are brief overviews of the *MCDM-23* method and software followed by a more detailed description of the method. The description concludes with a discussion of how to use the *MCDM-23* method in a design competition. For more details and a full description of the *MCDM-23* software, see the user manual.

The *MCDM-23* method in brief

The purpose of the *MCDM-23* method is to aid in organizing information required for decision-making. It consists of two main phases:

In the first phase, the participants (the design team or the judges in a competition) decide on the criteria they want to use and determine their relative importance. Since there are usually quite a few criteria, it is helpful to organize them into 5 to 8 main criteria each with several sub-criteria. This first phase should be done right at the beginning, before there are alternative designs to be considered. In trying out the method, the Task 23 participants came to the conclusion that this process of discussing criteria and agreeing on their relative importance was an extremely valuable activity in and of itself. It helped the group clarify their objectives. It got them going in the same direction with common objectives. Several participants expressed the opinion that this process was the *most* valuable aspect of the method. In this first phase, the group also establishes the scales that they will use later in scoring the various criteria.

In the second phase, the group uses the method to judge the relative merits of two or more alternatives. This is done by determining scores for each alternative for each criterion, using measuring scales defined in the first phase. In some cases this might require performing computer simulations to determine energy use. In others it might require estimating construction costs, determining probable indoor air quality, judging relative architectural merit, or forecasting how adaptable each scheme would be to changes in building use or clients. The scores are then aggregated into several overview presentations, (1) a single score for each design alternative design, (2) a star diagram for each alternative design that shows its scoring graphically, and (3) a bar chart for each design alternative that give more detail about the weighted results, and (4) summary worksheets that show the details and compare the alternatives side-by-side. Most groups are leery of basing a decision on a single score and want to see all of these outcomes.

The star diagram is one of the results of the evaluation. One such diagram would be produced for each alternative. By visual inspection of these diagrams, the group can get a quick understanding of the big picture. The diagram of the selected alternative might even make a good graphic to display in the completed building, showing how it performs according to all the relevant criteria.

In organizing these phases, it is recommended that the group designates one member to be responsible for organizing the steps and the information. This person becomes the "resident *MCDM-23* expert". Other members of the group do not need to become familiar with the mechanics of aggregating the information and running the *MCDM-23* software, but they do need to understand the principles involved so that they develop faith in the method. This means that they must participate in the first phase and review the results of the second.

The method proposed consists of six steps, as follows. The first three are carried out in the first phase, prior to initiation of design. The last three are carried out in the second phase, after generating schemes, when making the decisions:

Step 1. Select main design criteria and sub-criteria

Step 2. Develop measurement scales for the sub-criteria

Step 3. Weight the main criteria and sub criteria

Generate alternatives

Step 4. Predict performance

Step 5. Aggregate scores

Step 6. Analyse results and make decisions

During this process, criteria may be added, removed, or reformulated, which may require the team to go back and redo a part or all of the procedure several times. This should be considered a useful outcome, indicating that the discussion and analysis of the problem and the objectives has produced a deeper understanding of the design project.

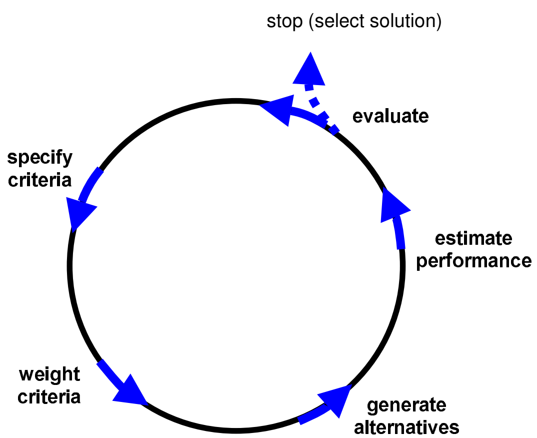
It is important to remember that the primary goal is not to provide definitive answers, but to enhance the ability of all participants to comprehend the problem at hand.

The *MCDM-23* software

Several of the steps in using the *MCDM-23* method require numeric manipulations, such as interpolating in tables, computing averages, normalizing a set of values, plotting pie charts, constructing worksheets, and plotting diagrams and bar graphs. Although a person could do all this work by hand or devise a spreadsheet to assist in the process, it would be a lot of effort that would have to be repeated each time the method is used. In order to make the method more accessible, Task 23 has developed a computer program that automates all the tasks that can be automated, taking the drudgery out of the process. This leaves the team free to carry out the judgmental work that cannot be delegated to a machine. The *MCDM-23* software is a Windows program written in Visual Basic. It is distributed on a CD-ROM and is non proprietary – anyone can use it and copy it free of charge. The source code is provided on the CD-ROM so that anyone so motivated can modify the program for their own purposes.

When to use *MCDM-23*

Several phases of building design, particularly during the early stages of design, tend to be iterative or cyclical in nature. A typical cycle is shown.



Any such design cycle might benefit from *MCDM-23*, both for structuring the design work and as part of the evaluation phase. It is recommended to use a trimmed-down or simplified version of the method during the early phases of design and then to use a fuller, more comprehensive version later in the process. In the early phases, a complete energy analysis may not be warranted, but would be required at a later phase.

As a practical matter, the full *MCDM-23* process might be reserved to the end of the initial or preliminary design phase. Typically, the designers produce two or more design alternatives at the end of this phase in preparation for a design critique. These would be fairly complete descriptions, with site layouts, architectural drawings/sketches, and cost estimates. This would be an ideal time to use *MCDM-23* to help in deciding which alternative to pursue into the design development phase. Or the team may elect to create a new design, choosing from the best features of the best alternates while avoiding the key problems with the leading alternative.

Step 1. Select main design criteria and sub-criteria

The client is the ultimate arbiter of criteria, but it will normally be necessary for the design team to discuss and interpret the client priorities and to add needed additional criteria before design begins, preferably at their initial meeting. Typically, many priorities are defined in the brief and the team priorities need to reflect those of the client. The importance of having the team specify criteria is *to foster the development of a common mission for the design team*, and *to have an agreed upon reference for evaluating the performance of design.*

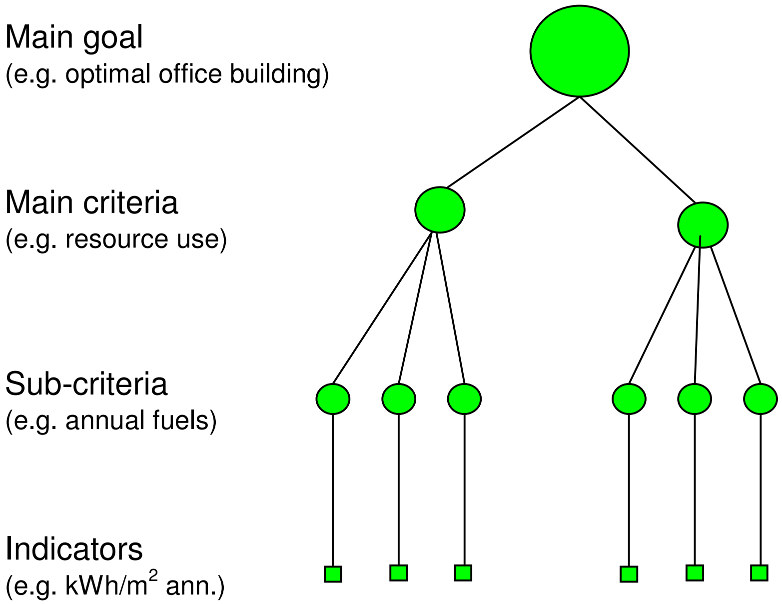
Although most of the work of criteria selection is done in the programming stage, criteria may be added, removed or re-formulated as the design proceeds. The number and nature of the criteria will vary from case to case. Checklists of criteria may be used to help the search and to ensure that no important issues have been overlooked. Some criteria will be quantifiable, such as annual resource use. Others will be qualitative, such as architectural expression.

In order to have a manageable number of criteria, the number of main design criteria should not be more than 8 and there should not be more than 8 sub criteria under any of the main criteria. A good procedure is to develop an exhaustive list first and then refine it by

1. eliminating criteria of little importance,
2. grouping those that remain into main categories,
3. selecting the titles for the main design criteria,
4. refining the sub-criteria.

The approach recommended is to start out wide with general, strategic criteria, and then narrow in, proceeding to specific criteria until a level is reached that is reasonable. More than 30 sub-criteria would probably be too many.

Describe, Select and Structure criteria



Example of main design criteria and sub-criteria

Main design criteria	**Sub-criteria**
Life cycle cost	Construction cost
	Annual operation cost
	Annual maintenance cost
Resource use	Annual electricity
	Annual fuels
	Annual water
	Construction materials
	Land
Environmental loading	CO_2-emissions from construction
	Annual CO_2 emissions from operation
	SO_2-emissions from construction
	Annual SO_2 emissions from operation
	NO_x emission from construction
	Annual NO_x emissions from operation
Indoor climate	Air quality
	Lighting (incl. daylight)
	Thermal comfort
	Acoustic
Functionality	Functionality
	Flexibility
	Maintainability
	Public relation value
Architectural expression	Identity
	Scale/proportion
	Integrity/coherence
	Integration in urban context

The list of main design criteria and sub-criteria for solar building design proposed by the IEA Task 23 participants is representative but not necessarily comprehensive when it comes to architectural issues. The list is included in the *MCDM-23* software as default criteria.

Examples of different design criteria

The exact selection of criteria will be context, and also design phase dependent. Even if the main design criteria are the same, the sub-criteria may differ from design phase to design phase. For instance:

In the pre-design phase, the criteria need to be quite general. These can be criteria like volume (versus cost), shape and orientation (suitability for daylighting), functionality (fitness to design brief), resource use, and environmental loading. At this point it may be appropriate to keep the discussion of architectural concepts as a separate discussion.

In the concept design phase, when certain decisions already have been made, more building specific criteria may be considered. These can be criteria related to the structure and the systems of the whole building, such as cost (life cycle cost), functionality (multifunctionality, modularity, flexibility), indoor climate, resource use, and compatibility with the (already chosen) architectural concept.

In the design development phase, yet more specific criteria may be applied. Still, some of the headings may be the same, and the criteria may be cost, energy use, other resource use, environmental loading, functionality, maintainability, structural independence, and compatibility with the architectural concept.

Basically, the method is applicable to any type of problem where decisions have to be based on multiple criteria. Completely different problems, outside the realm of architecture, will have completely different sets of criteria, indicating that the method is independent of the criteria chosen.

Step 2. Develop scales for the sub-criteria

A scale for each sub-criterion is necessary to be able to measure the performance. A measurement scale is a way to convert a value into a score. A value can be a number or a phrase, depending on whether the criterion is quantitative or qualitative. Quantitative values are used for criteria that can be measured directly with numbers, such as annual energy use, life cycle cost, or carbon emissions. Qualitative values are words or phrases that can be used to characterize how well a building scheme rates against a particular criteria where the rating is more a matter of judgement, not normally subject to quantification. These are quality issues, such as architectural expression or functionality. Some criteria can be characterized either way, such as indoor air quality, which can be either qualitative or rated based on a numerical value.

All criteria are ultimately converted to a qualitative scale, using the familiar scale of 1 to 10. The 1-to-10 scale is truncated at the bottom resulting in a 4-to-10 scale. It is possible to substitute other words for the descriptors, "excellent', "good", etc. In the 4-to-10 scale, the upper and lower ends have particular meanings:

<u>The upper end, a score of 10</u>, means that the building rates as "excellent". To be more exact, the 10 means that the building is the "best reasonable attainable" with regard to the particular criteria. This is a bit softer than saying that it is the best theoretically attainable. For example, it might be conceivable to create a zero energy building but double the cost of the project by purchasing PV cells.

<u>The lower end, a score of 4</u>, means that it is just marginally possible to construct a building that scores so poorly. For example, the maximum building energy use allowed by regulation could be the lower bound. One is not legally allowed to construct a building that performs worse than the regulation.

The next step is to create a *measurement scale* for each of the criteria, indicating the assessment of the merit of achieving particular scores. The scale should be divided into intervals that are felt to be equal; i.e. the utility of a unit step on the scale must be the same whether it is at one or the other end of the scale.

Score	Judgement
10	Excellent
9	Good to Excellent
8	Good
7	Fair to Good
6	Fair
5	Acceptable to Fair
4	Marginally acceptable

The process of creating measurement scales should generate much discussion, causing participants in the process to focus on the interpretation of the criteria they have defined in addition to assessment of options. It will often come to light that the same words have different meaning for different individuals, which can lead to a restructuring of the model. The process of setting end points on the scales can lead to an active search for alternative options, spurred by the feeling of "Can we not do better than that?"

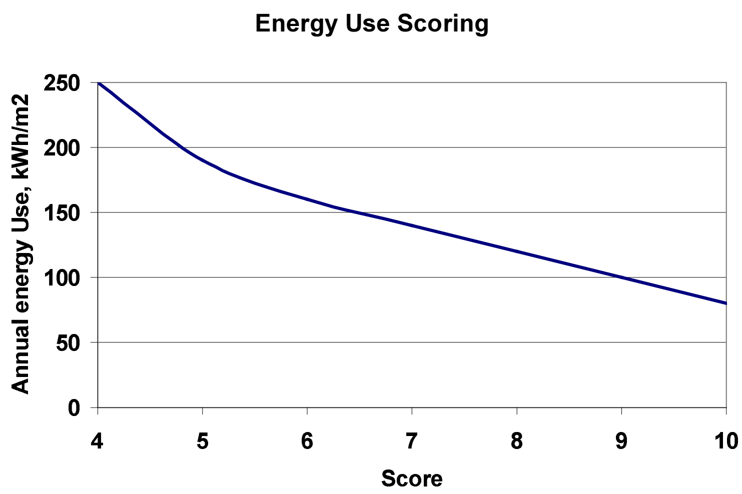
Scaling the objectives of a problem in this manner not only helps the design team arrive at uniform measurement scales but is also a way to define the general nature and context of the problem. The process of defining and constructing these measurement scales involves the collective participation of the entire team and allows each team member to express his or her own values and expertise to the group as a whole.

The development of measurement scales is facilitated in the *MCDM-23* software.

Example of measurement scale for quantitative criteria

Annual Energy Use

Score	Judgement	Annual energy use kWh/m^2
10	Excellent	80
9	Good to Excellent	100
8	Good	120
7	Fair to Good	140
6	Fair	160
5	Acceptable to Fair	190
4	Marginally acceptable	250



Note that the table can be non-linear, as seen in the graph. In this case the difference between a score of 9 and a score of 10 is 20 kWh/m^2 whereas the difference between a score of 4 and a score of 5 is 60 kWh/m^2, three times greater.

Example of measurement scale for qualitative criteria

Flexibility

Score	Judgement	Flexibility
10	Excellent	Different clients without changes
9	Good to Excellent	Different clients by: - moving adjustable partitions *or* - adding installations prepared for
8	Good	Different clients by: - moving adjustable partitions *and* - adding installations prepared for
7	Fair to Good	Different clients by rebuilding: - non-load bearing partitions *or* - some installations
6	Fair	Different clients by rebuilding: - non-load bearing partitions *and* - some installations
5	Acceptable to Fair	Different clients by rebuilding: - some load bearing partitions *or* - several installations
4	Marginally acceptable	Different clients by rebuilding: - some load bearing partitions *and* - several installations

The list on the right illustrates that if "excellent, good, fair ..." does not fit the situation, it is possible to create a table that better explains the meaning of the different values.

Step 3. Weight the main criteria and sub-criteria

Weighting the main design criteria.

The main design criteria weights reflect the central priorities of the project. The weights chosen will be critical in comparing alternative schemes. Although the client may be ultimately responsible for selecting the final scheme, he deserves help from the design team. It is useful for the team to evaluate schemes for presentation to the client and make a recommendation. In order to do this objectively, priorities are necessary.

There are different ways of eliciting weights. The grading method, works with the weights directly. The criteria weights are determined on a 10-point scale similar to the one used for scoring the performances. The decision-maker expresses the importance of criteria in grades on the scale 10, 9, 8,...4. The most important criterion receives a grade of 10. All the other criteria are compared to this, e.g. if a criterion is felt to be somewhat less important than the most important one, it receives a grade of 8.

Another method is a complex mathematical technique, the AHP method (analytical hierarchy process, developed by Thomas Saaty*). Although based on a rigorous theory, this method might seem opaque to a layman. It also sometimes exaggerates differences.

Both methods are included in the *MCDM-23* software.

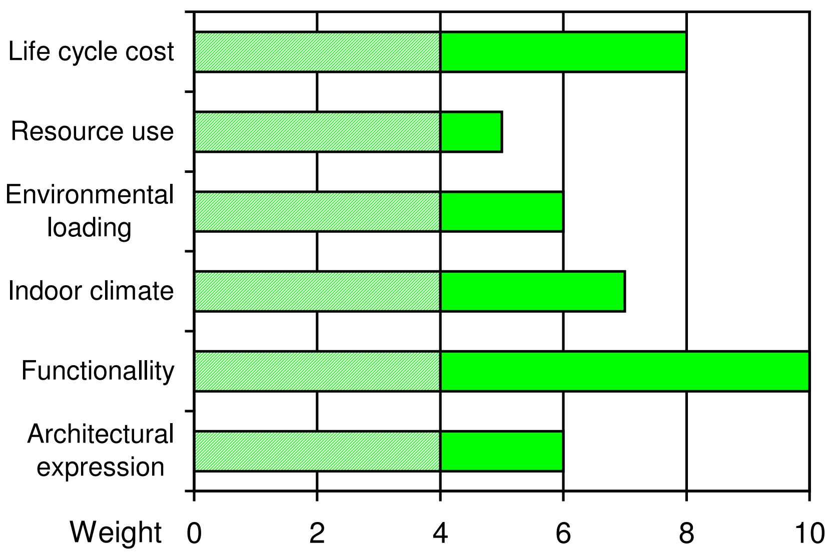
A useful tool is to graph the weights in a chart. One can then visualize the results. Participants who respond better to graphs than numbers (that is almost all of us) will find this attractive.

Weighting the sub-criteria

The procedure for weighting sub-criteria is the same as for weighting the main criteria. The most important sub-criterion is selected and the others are then compared to it using the 4-to-10 scale.

* Thomas Saaty, Reference to publication (Doug)

Grade	Relative importance (compared with the most important criteria)
10	*Of equal importance*
9	
8	*Somewhat less important*
7	
6	*Significantly less important*
5	
4	*Not important*



Generate alternatives

The responsibility for this task lies with the design team. Since the generation of alternatives is mainly a craft, little formal guidance can be given. Each designer will have developed their own approach, which sometimes carries a aura of mystique. It is important that the alternatives are generated keeping in mind the criteria and their relative importance. It may be wise to start out wide to test the extremes of the criteria and to be sure that a wide range of possibilities has been considered.

Step 4. Predict performance

The levels of predicted performance of the proposed solutions with respect to the criteria are determined. The performance prediction may be based on computer simulations, databases, rules of thumb, experience or expert judgement. The level of detail should be chosen based on an estimation of the available time and resources and the accuracy required.

Performance scores for the qualitative criteria must normally be decided by the team. It is best if the decision on performance score can be taken in consensus by the design team. In other cases, it might be necessary to do it by voting or by involving external experts.

The scores can be entered in the *MCDM-23* software for further computation.

Step 5. Aggregate scores

The simple additive weighting model is used to aggregate the scores into one score based on the criteria weights:

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

(Total score = sum of: Normalised criterion weight x Criterion score)

where S is the total score, m is the number of criteria, w_j is the normalised weight of the criterion, and s_j is the score for the criterion. The weights in the sum are first normalised by dividing the individual weight with the total sum of weights.

This is used first at the sub-criterion level to obtain the criteria scores and again at the main level to calculate the total score.

By this time in the process, all values have been converted to scores on the 4-to-10 scale. This uses a number defined earlier (10, 9, 8, … 4), each with an associated descriptor (excellent, good to excellent, good, fair to good, fair, acceptable to fair, and marginally acceptable). Conversion from indicators (kWh/m^2, etc.) has been done for each of the quantitative sub-criteria scores using the measurement scale.

This step can be done in the worksheet in the *MCDM-23* software. The procedure is used to perform both the aggregation of sub-criteria scores into a main criteria score and to aggregate the main criteria scores into one score that represents the overall performance of the building.

The worksheet in the *MCDM-23* software provides a way to inspect the results. It shows the individual values and corresponding scores for each sub criteria, the main criteria weighted scores, and the final scores.

Blind faith in a single final score will invariably mask the process and judgments that went into developing a total score. One important value of the worksheet is that it can be used as documentation of the selection process. This could be particularly important in a case of a public building, where it is important to clearly document the process and results.

Example of aggregating the scores of the sub-criteria under main design criterion: Life cycle cost

Sub-criteria	Weight	Norm. weight	Score	Main criteria score
Construction cost	10	0.40	9	3.60
Annual operation cost	8	0.32	7	2.24
Annual maintenance cost	7	0.28	5	1.40
Total: Life Cycle Cost	25	1.00		7.24

Example of aggregating the scores of the main design criteria to a total score

Main design criteria	Weight	Norm. weight	Score	Total score
Life cycle cost	8	0.19	7.2	1.37
Resource use	5	0.12	6.5	0.78
Environmental loading	6	0.14	5.8	0.81
Indoor climate	7	0.17	6.9	1.17
Functionality	10	0.24	8.1	1.94
Architectural expression	6	0.14	8.6	1.20
Total:	42	1.00		7.27

Step 6. Analyse results and make decisions

Present results

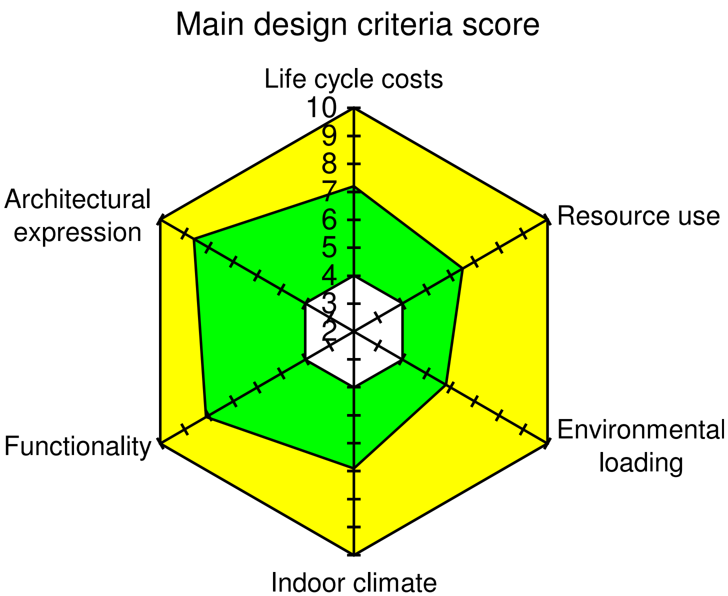
A star diagram is recommended for presenting the overall performance of an alternative. The generation of the star diagram is included in the *MCDM-23* software. In this diagram it is possible to show multiple dimensions, thus all the individual performance measures can be gathered into one picture. Each “finger” represents the scale for one criterion. The performance on each criterion is plotted on each “finger”. The centre of the star usually designates the minimum score of 4 for each criterion. The outer unit polygon represents the maximum score of 10 fore each criterion. Although the star diagram may be used to give an indication of the overall performance of an alternative, it should be used with caution. This is because the main criteria are shown as if they are all equal whereas weights might have been used in the final score computation.

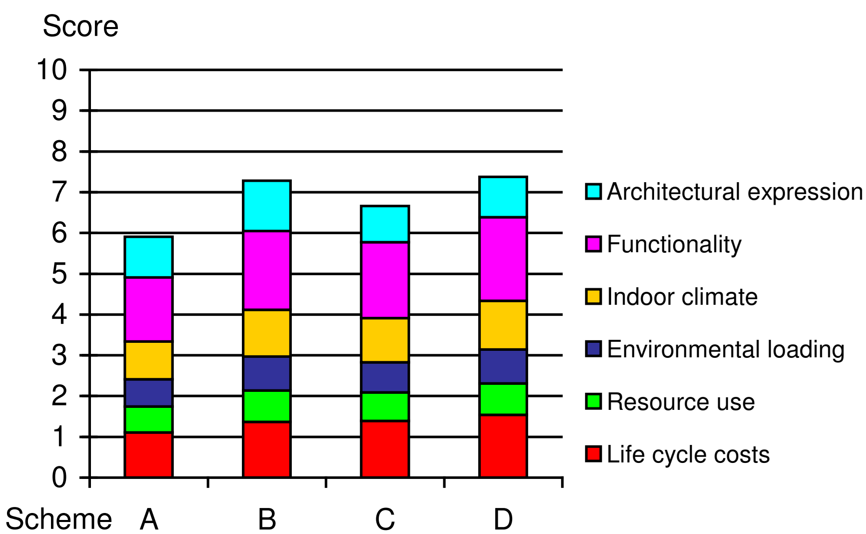
Discuss results

The team should study their results, come to a conclusion regarding their recommendation, and present this as their recommendation to the client for his or her final decision. If the presentation and logic are clear and if the team and the client were working toward commonly agreed goals, the conclusion will usually be evident.

It may be that at this point a new scheme should be developed that combine the best features of the leading scheme while eliminating some of its problems.

In any case, the most important use of the method is to structure the discussions and to help the design team reach a common understanding of the problem at hand and of the value of the various solutions. Thus, they will be able to make a better recommendation to the client.





Using *MCDM-23* in a design competition

Using *MCDM-23* in a design competition is very similar to using it in a design process. The difference is that it is a tool for the jury to use rather than for a design team.

Usually the competition will announce a set of rules and criteria ahead of time. This will define both the criteria to be used and the weights to be assigned by the jury in judging the entries. The jury normally meets, perhaps for the first time, after the deadline when all the entries have been submitted. Preferably, the jury members should participate in the process of defining criteria, measurement scales, and weights. The procedure for this is similar to that described for the design process.

The subsequent steps are also much the same as described for a design process, as follows:

1. The jury should review the criteria. If there are no sub-criteria, the jury can agree on some sub-criteria if they need to clarify the situation among themselves. For example, sustainability might be one of the criteria. In this case, the jury should certainly discuss what sustainability means to them, perhaps defining sub-criteria (if not already announced) that can serve as key attributes of a sustainable building, such as use of recycled materials, recyclability, minimum site disturbance, and groundwater drainage.
2. Weights should be reviewed and adjusted if necessary. Main criteria weights are often announced along with the rules. If sub-criteria have been defined by the jury, then these must be weighted. These first two steps will be very useful as communication tools to facilitate getting the jury off to a good start in overall agreement about the judging process.
3. Values must be determined. In some cases, it is impractical for the jury to do the required analyses themselves, such as calculation of annual energy use. In such cases, the burden should fall on the submitters of each entry to have made the calculations, telling how this was done. Another possibility is for a team of experts to meet ahead of time to do the calculations, which could be a lot of work. Many of the quantitative criteria will fall in this category, where the jury relies on outside expertise. For the qualitative criteria, such as architectural expression, the jury determine the values themselves – this is their area of expertise. In setting up the jury

process, the organisers should think through the process, making sure that credible values can be determined within the typical short time frame usually allowed for the judging.

4. Someone, either one of the organisers or a member of the jury, takes responsibility for running *MCDM-23* software. This is largely a technical role, perhaps best done by a person who has done it before. As values become available, he or she enters the values into the program and prints the resulting worksheets, star diagrams, and stacked bar graph.
5. The jury can either settle on the highest scoring entry, which would be logical, decide to select another entry, or adjust the process (values) to better reflect their priorities and judgements. The jury may decide to make their detailed results public or not.

It should also here be stressed that *MCDM-23* primarily is a means to organise discussions of the entries based on the multiple criteria specified in the competition program. It should not be used as the single means of selecting a winner, but should rather complement the open discussions taking place in the jury.

Participants

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