Eco-factor Method

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Report from the project: IDEEB
Intelligently Designed Energy Efficient Buildings
–assessment and control by an Eco-Factor system

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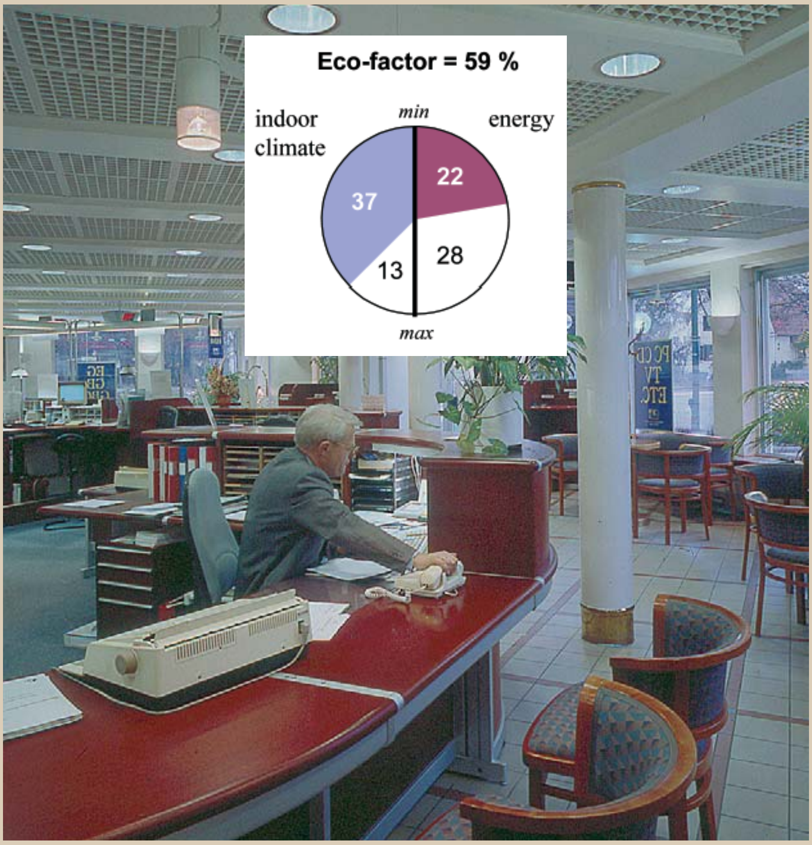

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Preface

This report is produced within the research project IDEEB, Intelligently Designed Energy Efficient Buildings -assessment and control by an Eco-factor system.

The holistic approach of the IDEEB project is to adopt comprehensive view. This considers the building itself and its installations as one energy system to achieve the required indoor climate at the same time as reducing environmental impact. Since each building is unique there are no all-encompassing solutions, and therefore the project aims to develop a concept (based on a Eco-factor) that describes the way of working to reach the goal.

The IDEEB project consists of three parts:

1. *A theoretical part* with separate developments of new guidelines and methods for the building process and design of a control system.
2. *A demonstration and improvement part* there the results from the first part should be tested, improved and extended in construction of four office buildings situated in different European climates.
3. *An evaluation and connection part*. Here all the improved results from the second part should be merged into a concept that would describe a way of working to achieve energy efficient buildings with good indoor climate and low environmental impact.

Unfortunately the market situation for construction of office buildings changed after the start of the project and therefore could only the first part of the project be performed. This means that the total project result consists of nine separate reports with theoretical background for guidelines and methods, which are ready to be tested in practice for improvements and extensions into a new way of working.

One part of the project deals with developing an assessment concept for an iterative design process of office buildings with integrated energy solutions. An Eco-factor method will be used for the assessment of the building’s energy related environmental impact and indoor climate. This part of the project has developed the Eco-factor method and defined its index system.

The IDEEB Eco-factor method has been programmed into one public software, which is a preliminary research version based on MS-Excel spreadsheet.

The authors would like to thank all IDEEB participants that have tested the method within their organisations and thereby have been able to assist with useful comments and suggestions for improvements. Especially we want to mention:
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Summary

This work is a part of the EU-Energie project IDEEB, ”Intelligently Designed Energy Efficient Buildings”. The principal objective with the IDEEB project is to develop new guidelines that will facilitate to overcome non-technical barriers for renewable energy sources and sustainable technologies, in order to achieve energy efficient buildings with good indoor climate and low environmental impact. To avoid the indoor climate problems that are seen all too often in contemporary office buildings, it is essential that energy optimisation is integrated with assessment of indoor climate. An improvement on one objective is only wanted if it does not have detrimental effects on the other.

One part of the project deals with developing an assessment concept for an iterative design process of office buildings with integrated energy solutions. A concept that will enable assessment and optimisation of energy sources and alternative technical energy solutions, where the assessment will focus on the energy use and its related environmental impact due to conditioning of the indoor environment in the building in the operation phase. An Eco-factor method will be used for the assessment of the energy related environmental impact and indoor climate. This report aims to develop the Eco-factor method and define its index system.

An indexing system has been devised that incorporates environmental effects of energy use with thermal and atmospheric indoor climate in a score on a common ”scale” from 0-100%, called the ”Eco-factor”. The ”Eco-factor” is calculated by weighted addition of sub-scores, which in turn are calculated by scoring functions based on indicators of physical properties (namely energy use, air-borne emissions, plus indoor temperature, velocity, and concentration fields). Several suggestions of weighting factors, based on a literature survey, are discussed.

Only the operative phase of the building life cycle is considered, since studies show that – with present building and energy practice - the operative phase accounts for the large majority of the energy related emission to the external environment. Thus, the main part of the energy related impact from a building can be assessed by calculation with a relatively small amount of input data.

It is the intention that the assessment concept with the Eco-factor should be used:

- By architects and engineers in the design of a building, for supplying a quick overview of the effect of changing key parameters as room height, air change rate, internal loads, control strategies, etc. This should allow for rapid iterations, showing the designers potential for improvements on either energy use or indoor climate, but at the same time highlighting perhaps unforeseen dangers, for instance of compromising indoor climate in order to improve the energy performance.

- For optimising the indoor climate and energy related environmental impact during operation of the building. The Eco-factor is based on physical properties that can be either measured directly, or programmed into a BEMS control system.

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1. Goal and scope

The main objective of the IDEEB-project is to develop a concept in order to build or refurbish energy efficient office buildings with desired indoor climate and low environmental impact. The approach is to consider the complete energy system of a building (the total system and functionality of the building and its installations).

One part of the project deals with developing an assessment concept that will enable assessment and optimisation of energy sources and alternative choices of technical energy-solutions, in the design of buildings with integrated energy solutions. The analysis will focus on the impact on the environment due to energy use for conditioning of the indoor environment, meaning that good indoor climate is the goal, and that energy related environmental impacts are unwanted side effects.

An Eco-factor method will be used for the assessment of the energy related environmental impact and indoor climate. This report aims to develop the Eco-factor method and define its environmental indexing system.

1.1 Relation between energy use and indoor climate

To avoid the indoor climate problems that are seen all too often in contemporary office buildings, it is essential that energy optimisation is integrated with assessment of indoor climate. Improvements are only wanted if they do not have detrimental effects on indoor climate. Examples:

- Large glazed facades facing south to improve passive solar energy, leads to overheating problems in summer.
- Natural ventilation to decrease electricity use, leads to inadequate indoor air quality when the differences between indoor and outdoor conditions are too small to give sufficient driving forces.

Problems in newer office buildings, when such arise, are often connected to:

- The design and control of the building as an energy system
- Design and control of the indoor environment (in terms of temperature control and indoor air quality).
- The often interconnected nature of the above two issues, since issues as internal and external heat loads, temperature, and air change, affect both energy use and indoor climate.

The IDEEB project concentrates on creating an assessment concept that can be useful for assisting building designers in creating solutions to these problems. To be of any practical use, the Eco-factor tool requires the possibility to, relatively quickly, have a visual and easily understandable representation of the environmental effects of different alternative choices.

Only indoor climate aspects that are closely interrelated with energy use, are considered:
- Thermal comfort => temperature range => heating, cooling
- Indoor Air Quality => ventilation => electricity

Other examples of categories that could theoretically be included in an energy and indoor environmentally oriented tool, as it is in some related assessment tools (see Chapter 1.3.2 and Appendix A):

- Lighting, daylighting => electricity consumption.
- Acoustic environment => influences choice of materials, constructions, and geometry.
- Embodied energy in building.
- Waste

For the time being, we have included lighting in the energy part, but not in the indoor climate part of the Eco-factor. It is our impression, from discussions with architects and from the literature study during the first part of the IDEEB project (Bjørn and Brohus, 2003), that the problems of daylighting and artificial lighting are already very much at the center of focus when architects are designing buildings, and that the architect appears to have appropriate ways and means of making informed choices.

The energy benefit of daylighting and efficient artificial lighting is included in the calculation of energy use for operation of both lighting and HVAC systems. The particular choice of artificial lighting where it is necessary, impacts upon the HVAC system sizing. Good selection of energy efficient lighting and diffusers can result in reduced cooling load as well as lower lighting power. The Eco-factor methodology reflects the energy benefit of daylighting and efficient artificial lighting, since electricity use for lighting is included in the total energy use for operation, and since heat from lighting should be included in load calculations for HVAC design.

1.2 Environmental Impact Categories

Calculation of emissions and assessment of environmental impacts from energy use will be based on Life Cycle Assessment (see Figure 1.1), but in the form of inventory lit of emissions with key indicators for different energy sources, which in turn are calculated by existing LCA tools. The main purpose of these tools is the creation of an inventory list, which sums up the material and energy flows that go *in* (resources) and *out* (emissions, energy, waste) of the technical system, from which can be calculated by normalization the impact potential on relevant environmental categories. Such tools usually also include some form of weighting scheme, to assist in the interpretation of the results.

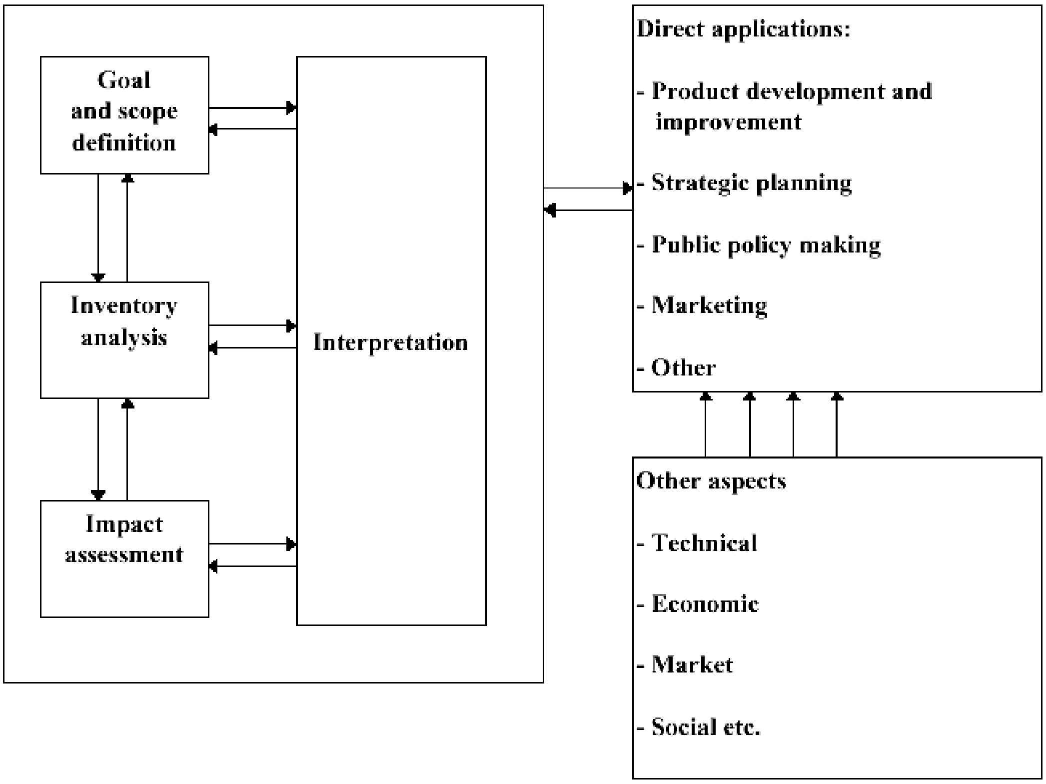

Figure 1.1 Phases of an LCA, ISO 14040.

As Figure 1.1 shows, the results of the analysis may be used by different actors. The intended use of the analysis – which decision(s) must be made – will determine the formulation of the goal and scope definition. Different actors have different goals and points of view, and different need for information. They will be bound to be limited or influenced by a variety of other, interacting considerations, for example:

- Technical (environmental and non environmental) (functionality, technical guaranties, maintenance, comfort, health, air water & soil pollution, waste, resources, relation between the building and the site, architecture & landscape).
- Economic (investment cost, running cost).
- Marketing possibilities.
- Social and Political (environmental requirements, public health, quality of life, conservation of the natural and built heritage, territory development, socio-economic stakes, image & exemplarity, conflict management).

It is also important to define, just what aspects of the interaction between the technosphere (the building and the activities connected to it) and the biosphere ("nature") are to be assessed, and in what phases of the life cycle since a very large number of possible interactions exist.

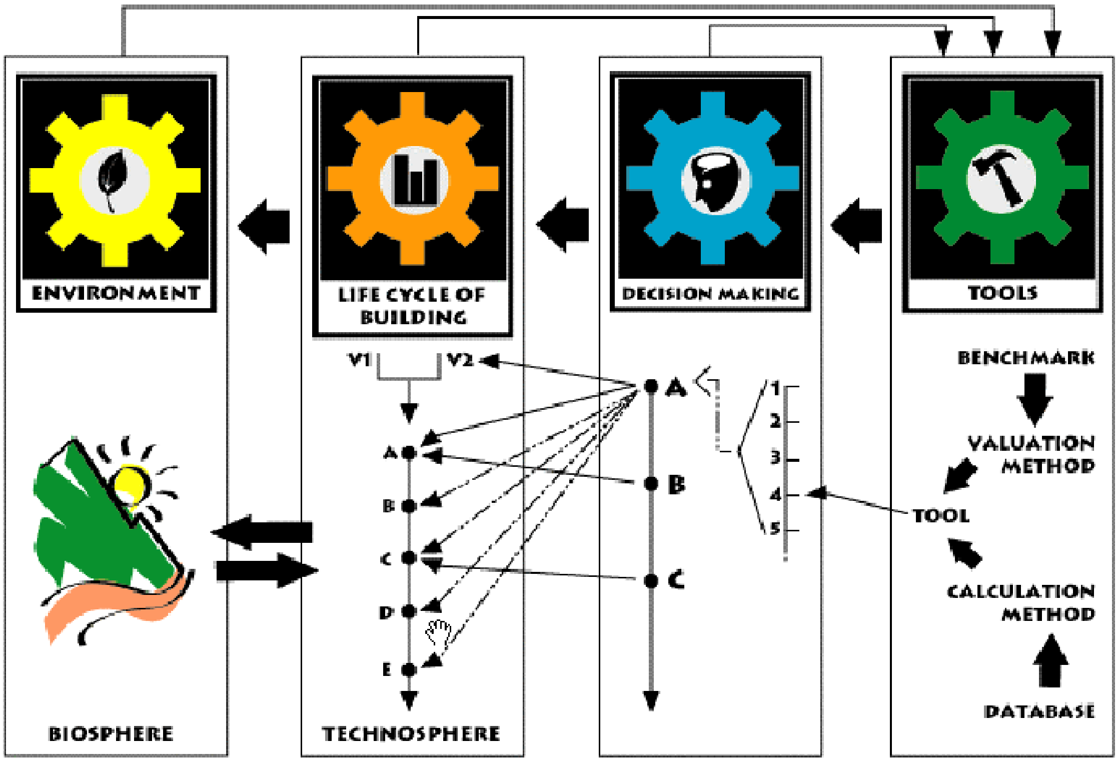

Figure 1.2 Schematic representation of the paradigm for an environmental assessment tool. (IEA ECBCS Annex 31)

The environmental impact categories in an LCA could typically include:

- Materials, especially scarce non-regenerative resources: fossil fuels, certain minerals.
- Energy, especially combustion of fossil fuels and nuclear power.
- Toxicity
  - Human.
  - Environmental.
- Working environment: dust, noise, vibrations, hazardous chemicals.
- Indoor environment, e.g. emissions from materials.

The categories addressed in the Eco-factor are:

- Energy related environmental impacts, due to energy use during operation
- Indoor Environment, including
  - Thermal comfort
  - Atmospheric comfort, IAQ

Only the operative phase of the building life cycle is considered.

- Studies show that – with present building and energy practice, the operative phase accounts for the large majority of the energy related emission to the external environment (see also Chapter 2.2.1). Thus, the main part of the energy related impact from a building can be assessed by calculation with a relatively small amount of input data.

There are many other important environmental issues in relation to buildings. These however fall outside the scope of the IDEEB Eco-factor. Some important examples:

- Use of Land
- Use of non-renewable and/or over-exploited raw materials
- Waste potential
- Water

An example of a non-technical barrier is that building decision makers often believe that sustainable technologies will indeed reduce the environmental impact, but that it will cause high investment costs or an inadequate indoor climate. Apart from considering architectural, technical, and environmental issues, economic planning must always be made in parallel, meaning that lifecycle costs must be calculated as part of the design process. Since investment costs are fluctuating, in time, in different European countries and with the volume of production, the cost analysis requires a different and separate approach. For this reason, we have considered inclusion of cost to be impractical as an integral part of the Eco-factor itself, which aims only to quantify physical properties of the building related to its operation phase. Cost analysis is, however, considered as part of the extended assessment and design concept being developed, see also Chapter 4.2. Perhaps at some stage the Eco-factor methodology results could be combined with those from a costing software package to help identify the most effective eco-investments. Relative costs between different schemes might be used to indicate which is the best investment in terms of improved internal and external environment per unit of expenditure.

1.2.1 Energy related environmental impacts

All use of energy will in some way cause impact on our environment. The impact will arise either directly when using the energy source or indirectly at extraction, production or transportation of the energy source, and at construction of means of transports and/or energy plants. Emissions to air, water and soil, use of natural resources and production of waste leads to environmental impacts at local, regional and global scales. Below are the most important environmental impacts due to emissions to air, which accounts for the large majority of the material flow from energy production based on fossil fuels or renewable energy sources (Wahlström et al., 2000 and 2002). Indicators of these impacts for specific energy sources are the input to calculate the Energy Eco-factor. Apart from impacts from emissions, energy use will affect use of natural sources, exploitation of ground, and production of waste.

Nuclear energy is a source of radioactive radiation and waste, which are the most important environmental impacts from nuclear power since it otherwise produces low emissions. This is difficult to quantify in the same way as the emissions to air. For this reason, the environmental impact potential from nuclear energy can be considered also with additional aspects, see Chapters 2.2.7 and 2.2.8.

Global warming

The solar radiation that reaches the earth will gradually return to space as heat radiation. Gases in the atmosphere will absorb some of this heat radiation and re-emit it to the earth. This is called the greenhouse effect and it is thanks to this we have a pleasant temperature on earth. The accumulation of greenhouse gases has been increased over the past few centuries by human activities. This may lead to an increase of the earths' mean temperature of several degrees during the next century due to the strengthened greenhouse effect. Such a global warming, as well as sudden regional climatic changes, will lead to several serious consequences on the natural eco-system and human settlements. The most important human contribution to the global warming impact is attributed to the combustion of fossil fuels such as coal, oil and natural gases. Usually carbon dioxide is mentioned as the contributor for increasing the greenhouse effect, but methane and dinitrogen oxide are also important contributors caused by energy use. Global warming affects the environment on global scale.

Acidification

Sulphur dioxide and nitrogen oxides emitted to the atmosphere will oxidize to acids. The acids will dissolve in water drops and reach the ground as precipitation that will cause an increase in acidity of ground, groundwater and surface water. Acidic precipitation can be more or less harmful depending on soil, disintegration of the ground and vegetation. For example on ground rich in lime, the acidic compounds will be neutralized, but large areas of the earth are, however, sensitive to acidification. Acidification has consequences on increased fish mortality in lakes in Scandinavia and central Europe, depletion of coniferous forests in many places in Europe and the USA, and corrosion damaged to metals and disintegration of surface coating. Emissions of sulphur oxide are mainly caused by energy production and industrial activity while nitrogen oxides mainly are due to traffic and energy production. The sulphur emissions in north Europe have decreased considerably during the last years due to use of fuels that contain less sulphur. Acidification affects the environment mainly on regional scale.

Photochemical ozone formation

The ozone in the troposphere (0 km – 10 km), the so called photochemical ozone that is harmful for humans and vegetation, has during the last century more than doubled in concentration in central and northwest Europe. This is in contradiction to the natural ozone in the stratosphere (10 – 40 km) that is decreasing and is essential for the life of earth. Photochemical ozone formats through oxidation of volatile organic compounds and carbon oxide by influence of light from the sun in presence of nitrogen oxides. Photochemical ozone has directly health effects on humans as headache, irritations in eyes and respiratory difficulties. Vegetation is affected by disturbed metabolism, accelerated ageing and influenced photosynthesis causing growth to decrease. The most important contributor to photochemical ozone formation is road traffic but also energy productions and industrial activities are important contributors. Photochemical ozone formation affects the environment both on local and regional scale.

Eutrophication

Eutrophication, or nutrient enrichment, occurs when an area receives too large supply of nitrogen or phosphorus. These substances are necessary and normally support growth, but too intensive concentrations may cause harmful effects on vegetation and animal life. Some vegetations and animals will breed while other will be eliminated. In the ocean eutrophication contributes to an increase in fast growing algae, which will cause oxygen lack in the bottom, which in their turn will cause dead bottoms. The human contribution to eutrophication is mainly from agriculture and wastewater treatment plants but also from combustion at energy production. Eutrophication affects the environment both on local and regional scale.

Fine particles

Resent studies during the 1990's have shown that air-pollution concentrations that today are common in Europe are harmful. Fine particles that penetrate directly into the lungs may cause allergies, cardiovascular and respiratory diseases as well as cancer. Fine particles generates at combustion of coal, oil and bio fuels and also from internal combustion engines, especially diesel engines. It is therefore also important to consider emissions of fine particles as an environmental impact caused by energy use. Particles that are less than 10 µm (PM10) are possible to inhale. The lifetime of fine particles in the atmosphere is days or weeks, and they can travel by air thousands of kilometres. Fine particles pollution affects the environment both on local and regional scale.

1.2.2 Indoor Climate

"Indoor climate" can be defined as the sum of all the factors (related to a building) that affects our feeling of well-being. In its widest sense, indoor climate is a very multi-disciplinary and diverse field. Important factors are physical or chemical quantities directly connected to the building and the air inside it, which cause an impact on the human body. Human perception and physiology is also an important part of it all, and psychological and social factors (such as stress) can influence these human factors.

The most serious health problems are related to impacts of a chemical nature, namely radon (from the ground). Also, a growing concern has developed that indoor pollutants may be a contributing cause to lung cancer and asthma (Samet, 1993). Choice of materials for indoor surfaces, sealants and waxes, glues, insulation materials, etc. may play a role here, as well as furniture and machinery, for instance PCs, printers, photocopiers, etc. However, not much is known for sure.

Much of this is a choice of avoiding potentially dangerous materials. Public and private labelling systems are the main information sources here. When problems of directly toxic or noxious substances is dealt with, there still remains the issue of indoor air quality (IAQ) and thermal comfort, which are related to issues such as the use of the building (for instance number of people per square meter), the climatic design of the envelope, outdoor climate, HVAC systems and controls, etc., and as such directly connected to the core issues of the IDEEB project. The Eco-factor reflects the quality of the atmospheric and thermal comfort in terms of sensory perception (expressed in a negative sense as "degree of dissatisfaction").

Source strength of pollution sources are included in the Eco-factor through calculation of olfactory perception of the indoor air quality. Typical source strengths for materials and for mechanical ventilation systems can be found in the literature. Source strengths of specific materials can also be estimated by sensory evaluation by a trained panel, but this is an expensive method. If not possible to estimate source strength for materials, pollutant concentrations must be calculated by assuming that human beings are the main pollution source, using CO_2 concentration as indicator. CO_2 concentration is also a viable indicator for use in control systems, since it can be measured continuously, automatically, and relatively inexpensively.

Sensory perception of indoor climate is perceived as a serious problem by millions of people all over the world. Most people spend 80-90% of their time indoors, and studies covering thousands of buildings have documented that complaints of dry, stuffy, or smelly air are commonplace, as well as complaints of actual sickness. The following symptoms are observed in buildings with a reputation of bad indoor climate:

- General symptoms: headaches, unnatural fatigue, malaise, or dizziness.
- Mucous membrane symptoms: irritation of the eyes, nose, or throat.
- Skin symptoms: red, dry, itching, or scaling skin.

These symptoms are so widespread that the World Health Organisation (WHO) has given them the generic name, Sick Building Syndrome. Apart from the obvious humanitarian reasons for solving this problem, research has proved that the indoor climate has a significant impact on the mental and physical abilities of people. When people are not comfortable, their performances deteriorate. (Jantunen et al., 1997.)

Levels of expectation regarding indoor climate

In the IDEEB assessment methodology, we will operate with three pre-defined levels of expectation, as described in CR 1752 (1998):

A: High level of expectation
B: Medium level of expectation
C: Moderate level of expectation

Limits for complying with each of these levels will be shown below for thermal and atmospheric comfort, respectively. The approach is discussed in more detail in Brohus et al., 2004.

The physical factors defining thermal and atmospheric comfort are measurable. Below follows a short description of each category and its indicators.

Thermal comfort

For the purposes of building design, comfort is defined negatively as the absence of any form of thermal stress. The definition of thermal comfort will follow the established guidelines of ISO 7730, 1991.

The standard is mainly based on the work of P.O. Fanger, who used a deterministic analytical model to describe a stationary heat balance for a person, expressed in the “comfort equation” (Fanger, 1970). The analytical model has been fitted to empirical data from a large number of laboratory experiments.

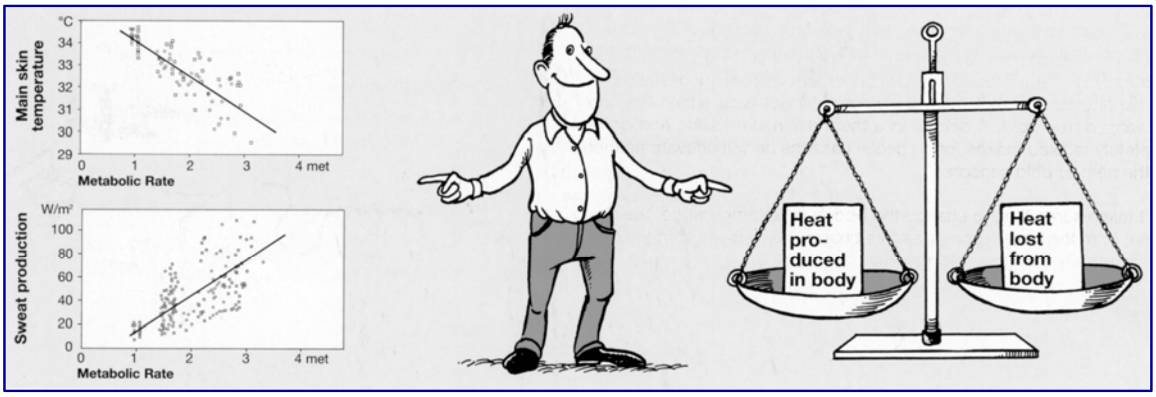

Figure 1.3 Prediction of thermal comfort is based on a heat balance, where heat produced in the body by the metabolism is lost by convection, radiation, conduction, and evaporation. (Picture: Brüel &Kjaer, 1997.)

To predict thermal comfort of a person with the comfort equation, it is necessary to have some knowledge of several physical properties of the environment surrounding the person as well as knowledge of the use of the location in question, i.e. the expected behaviour of the person regarding activity level and clothing.

Environmental parameters:

- Operative temperature, which is a weighted sum of:
    - Air temperature, the temperature of the “ambient” air, i.e. close to the person, which together with air velocity (see below) is responsible for convective heat loss from the body, and
    - Mean Radiant Temperature, as defined by the surface temperatures of the internal surfaces weighted by their angle factors. Heat loss due to long-wave heat radiation from body to surfaces.
- Air velocity, or mean air velocity. Heat loss to convection and evaporation from skin surface, sweating.
- Relative Humidity. Potential of ambient air to promote heat loss through evaporation (sweating and breathing).

Use of location, physiological factors:

- Activity. Internal heat production due to the metabolism of the cells in the body. Human Beings are warm-blooded, demanding constant internal temperature (37 °C) in body core. As a result, the body must loose more heat to surroundings at higher level of activity, in order to maintain constant temperature.
- Clothing. The insulation value of the clothing obviously is important for the overall heat balance of the body. To ensure comfort, higher insulation values means that the operative temperature should be lower, and vice versa.

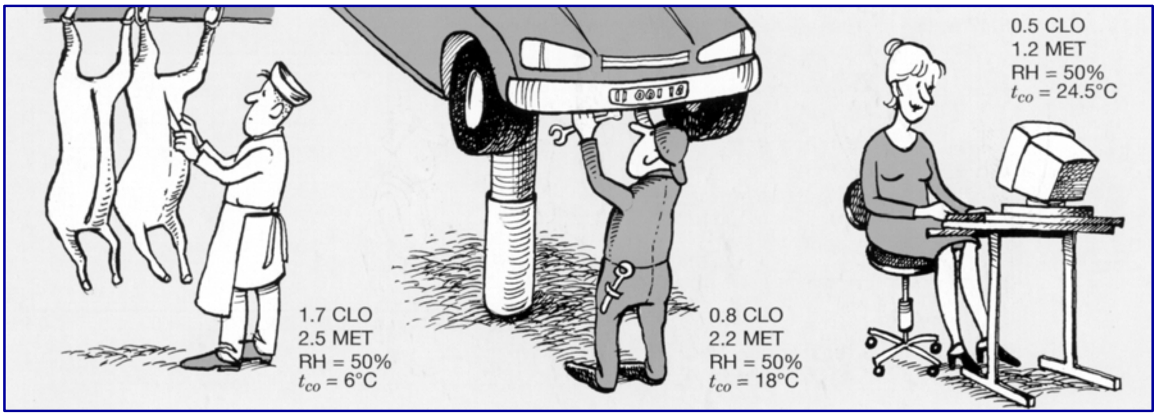

Figure 1.4 Different clothing and activity results in different requirements for operative temperature in order to be in thermal balance, t_{co} . (Picture: Brüel &Kjaer, 1997.)

Local discomfort

Even if the body is in thermal balance as a whole, it is possible to be uncomfortable due to local cooling or heating of parts of the body. The effects include:

- Draught. Local convective cooling of the skin. High turbulence intensity aggravates the problem.
- Vertical air temperature gradient. We find it uncomfortable if there is too large temperature difference between the air at our feet and our head, respectively.
- Radiant temperature asymmetry. If we are surrounded by surfaces, which have different temperatures in an “asymmetric” way – for instance warm ceiling and cold floor – this is perceived as uncomfortable, if the temperature difference is too large.
- Warm or cold floors. The feet are heated/cooled by conductive heat transfer to the floor. This is mainly a problem if a person has bare feet or very poorly insulating footwear like stockings, - which is usually not the case in office environments - or if the floor is unusually cold or warm, due to for instance floor heating or cooling systems.

Atmospheric comfort

Atmospheric comfort is mainly concerned with pollutants in the air. These may come from a variety of sources: the people themselves (body odour, bio effluents, CO_2), from the building materials (VOCs and other chemical compounds), from the building ventilation systems (dust in filters and ducts), from microorganisms living in building fabrics, carpets etc. (mould, fungus, mites), or from activities or processes taking place in the building.

The best way to avoid these pollutants is to minimize the production of pollutants, “source control”. However, this is not always possible, or only possible to a certain extent. To ensure comfortable conditions, ventilation is always necessary in order to remove or dilute the contaminant. One must also consider that the outside air may also be a source of pollution.

The personal exposure, meaning the concentration of a pollutant that is inhaled by humans, depends namely on the following factors:

- Contaminant type and source strength
- Air flow rate – larger “dilution” means lower concentration and better IAQ. Note that larger air flow rate also usually means larger energy consumption.
- Ventilation type and effectiveness. Depending on the geometry and use of the room, and depending on which type of pollutant is predominant, different ventilation principles may be applied. The difference on personal exposure may be considerable. (Brohus and Nielsen, 1996.)
- Activity of persons. The personal exposure depends not only on the general flow characteristics of the room, but also on local airflows close to the body, and of the interaction taking place between general and local air movements in the room. Movement of the body and limbs can be important, as can also the respiration flow. (Bjørn and Nielsen, 2002).

1.3 Functional demands for assessment tool

Environmental assessment tools must integrate environmental criteria - such as those described in Chapter 1.2 - into the existing design process. This is not easy, since building designers already must integrate many conflicting criteria to arrive at a satisfactory solution for all the parties involved in the building process. Every new layer of decision criteria adds complexity to the design process, and reduces the degrees of freedom, which can be seen as an unwanted restriction. The application of tools also requires additional economic resources, time, and expertise. If environmental assessments tools are to become commonplace in building design, the additional complexity and cost should be minimized as far as possible.

The project Energy Related Environmental Impact of Buildings (IEA ECBCS Annex 31), has made some fundamental analysis of environmental assessment tools for the building sector, and has been an important inspiration source for defining the functionality of the Eco-factor method.

IEA ECBCS Annex 31 states the following about assessment tools: “Tools should be:

- **honest**, in that issues to be measured truly have a detrimental effect on the environment,
- **easily adaptable** to specific buildings and locations,
- **capable of quickly ranking results**, so that trivial issues can be dismissed, and
- **transparent in their assumptions**, and especially in regards to the weighting given to different environmental issues like human health, ecological health, resources consumption.”

Also, clear indications of cause-effect relationships are necessary, in our view. When presenting results, it should be apparent what aspect of the design is causing poor performance.

1.3.1 Intended users of the tool

Different actors involved in a building project are the main intended users of assessment tools. Although organisation varies according to country, company, or even from project to project, the actors can nevertheless be grouped into 5 categories (IEA ECBCS Annex 31):

1. Collective interest (elected representatives, administrations, agencies, regional and local authorities, institutions, associations)
2. Operational decision-making (development companies, building owners, backers)
3. Design (prime contractors, architects, engineering firms, town planners, landscape engineers, quantity surveyors)
4. Execution (manufacturers, contractors, verification offices), and
5. Use & operation (service providers, building managers, users, insurers)

The IDEEB Eco-factor has been developed mainly with design in mind, even if it is intended to also be used for environmental optimisation of choices made by control systems. The intended users for the Eco-factor tool and their specific requirements are:

- Architects: rapid iterations, quick decisions, visually based
- Engineers: objective and detailed information, decisions based on figures and numbers, sensitivity studies.
- Contractors: score tied to information about average/best practices and standards.

Engineers like to know that the tool has been functionally verified and by what authority. The current trend in engineering is for all specifications, calculations and procedures to be in accordance with national standards, international standards or nationally recognised professional institutions. Wide acceptance of the Eco-factor by construction professionals would mean therefore that it must achieve such a status. For this reason, the Eco-factor method bases itself as far as possible on standard methods, described in for instance European and/or ISO standards, since these are already recognised and used by the building community. No novel methods for calculating for instance energy use, thermal comfort or environmental impact are introduced, only an assessment framework to assist in decision-making.

1.3.2 Related tools

The literature study connected to this work has shown us many examples of already existing environmental assessment tools that take into account several or all of these categories, but in different ways, meaning with different intentions of use. Some of the most well-known of these have been an important inspiration source, and we have drawn some useful aspects from them, according to the goal and scope of the IDEEB project.

- Green Building Assessment Tool (International)
- LEED (USA)
- Escale (France)
- BREEAM 98 for offices (UK)
- MCDM-23 (International)
- Energy-10 (US)
- EPS (Sweden)
- Eco-indicator 99 (the Netherlands)

Several more tools have been studied, which are listed in Appendix.

Green Building Assessment Tool

Green Building Challenge is an international collaborative effort to develop a building environmental assessment tool that exposes and addresses controversial aspects of building performance and from which the participating countries can selectively draw ideas to either incorporate into or modify their own tools. Green Building Challenge 2002 is a continuation of the GBC '98 - 2000 process and a multi-year period of review, modification and testing of the GBC Assessment Framework and Green Building Tool (**GBTool**) - the operational software for the assessment framework (Cole and Larsson, 1999).

LEED

Leadership in Energy and Environmental Design Green Building Rating System, developed by the U.S. Green Building Council. Aims to provide a national standard for what comprises a “green building”. Through its use as a design guideline and third-party certification tool, it aims to improve occupant well-being, environmental performance and economic returns of buildings using established and innovative practices, standards and technologies, (US Green Building Council, 2001).

Escale

Escale is a method allowing to assess and follow-up the environmental performances of a building project at the design stages. It is designed to be adapted to the iterative design process, to the language of decision-makers, and to provide understandable and interpretable results. It is structured by 11 main criteria, declined in sub-criteria that represent the impacts on the outdoor environment and on the users' comfort and health. An assessment module corresponds to each sub-criterion. The final result is a partially aggregated profile giving performance scores (Gérard et al., 2000).

BREEAM

Building Research Establishment Environmental Assessment Methodology — originally developed in 1990 by the Building Research Establishment (BRE). BREEAM is focused on providing a credible, transparent label for buildings based on best practice. It may be applied either at the design and refurbishment stages, or for existing buildings in operation. BREEAM awards an environmental label after assessing buildings against a range of environmental issues covering the impacts of buildings on the environment at global, regional, local and indoor levels. For each issue there are a number of ‘credits’ available. Where buildings have attained or exceeded various benchmarks of performance, an appropriate number of credits is awarded. For energy there are 15 credits available, depending on the level of emissions of carbon dioxide (CO_2) relating to energy consumption in the building. Overall, more than 100 credits are available. The philosophy of BREEAM is always to reward positive steps taken to improve the environmental performance of buildings, a feature much valued by clients. The number of credits attained is interpreted in the form of an overall rating of Excellent, Very Good, Good and Pass. (Yates et al., 1998.)

MCDM-23

MCDM means “Multi-Criteria Desision-Making”. The purpose of *MCDM-23* 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.

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 criteria, using value tables 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. (Balcomb et al., 2001)

Energy-10

Energy-10 is a recent software product completed in 1996 through a partnership of the Passive Solar Industries Council, NREL, LBNL, and the Berkeley Solar Group with funding from DOE. The aim of the program is to provide a user-friendly simulation tool for the design of passive solar strategies in small and medium-sized buildings. Energy-10 was developed with a building industry task force that included architects, engineers, builders, and utility representatives. The program is geared toward buildings of 1000 m^2 or less. The simulation engine of Energy-10 is a two-zone network model that runs on an hourly time-step, and includes passive solar and energy-efficient strategies as daylighting, solar orientation, thermal mass, ventilation, and ground-coupled cooling. Because the objective of Energy-10 is to encourage architects and engineers to incorporate passive solar design strategies in the early design phase of a project, the user interface requires a minimum number of inputs and has an Auto-Build feature that automatically generates two building files at once — one for the proposed design and the other for a generic reference design of the same size and usage pattern. The Auto-Build feature assists users in quickly evaluating the merits of a proposed design or design strategies (Energy-10, 1996).

EPS

The environmental assessment method EPS (Environmental Priority Strategies) expresses the additional environmental load that a resource use, a pollutant, a material, a process or an activity will cause during its complete lifecycle. The value of the environmental index is based on the influence of one or several of the five protection objectives: biological diversity, human health, the ecosystem’s reproducibility, natural resources and aesthetic values. The impact of the protection objectives is valuated after how much money the inhabitants in the OECD-countries are willing to pay in order to restore the protection objectives to their reference condition (the condition in 1990). In other words is the valuation based on the inhabitants in the OECD-countries willingness to pay in order to avoid an environmental change. The environmental load is expressed in ELU (Environmental Load Unit), (Steen, 1999 and Ryding et al. 1998).

Eco-indicator 99

Eco-indicator 99 is mainly based on lifecycle analysis that is supplemented with a concept of so called eco-indicators. The eco-indicators are an aggregated (~ added to a total from all contributions) measure on the environmental load that is raised at manufacturing of for example a material or from a process. The result from the inventory analysis is transformed to damage factors with three damage categories; human health, ecosystem quality and resources. The three damage categories have different units and are therefore normalized and thereafter weighted into one single indicator. The weighting factors are defined by a written panel procedure among members of a Swiss discussion platform on LCA, and are thereby subjective and cannot be considered to be representative for the average European. The standard Eco-indicator value can be regarded as dimensionless figures. As a name the Eco-indicator point (Pt) is used. The value of 1 point is representative for one thousandth of the yearly environmental load from one average European inhabitant* (Goedkoop and Spriensma, 2000).

*By normalizing with the environmental load from one person, it is possible to have the same unit for environmental loads of very different nature, and to have a unit that has some intuitive meaning. (Wenzel and Hauschild, 1997) also use division by inhabitants in the “EPID” method, but differentiate between the scales of the normalisation area. Global impact categories are normalised by global average personal equivalents, while regional impact categories are normalised by regional average personal equivalents.

1.3.3 Typology of tools

Trusty (Trusty, 2000) suggests the following typology regarding tools for assessing environmental concerns regarding buildings:

Level 1: Product comparison level
For making choices regarding building materials at the procurement stage. Comparative environmental profiles for building products. Level 1 tools can be used to calculate input for level 2 tools.

- General LCA tools
  - Example: SimaPro (NL)
- Database with pre-calculated data from LCA of common building materials
  - Examples: BEES (USA), BEAT (DK)

Today several environmental assessment methods are used in the world in order to give environmental aspects of different applications. These are designed for example to give environmental priority strategies in product development, e.g. EPS (Steen, 1999 and Ryding et al. 1998) or Eco-indicator 99 (Goedkoop and Spriensma, 2000). Some of them consider the same substances as in the Eco-factor method and have defined an assessment index for each substance. The index describes the magnitude of the environmental effect caused by the substance. In most methods, the index is set by considering the environmental impacts by effects on global warming, acidification, etc., and their related impacts on human health and the quality of the ecosystem.

Level 2: Whole building tools
The scope is the whole building, but not all subjects are addressed.
Typical examples are tools for evaluating building energy use, lighting/daylighting, or LCA inventories. Typically intended for use by the design team to scan alternative technical solutions iteratively. Outcome is data-oriented and objective, and adhere to formal technical standards. The LCA-oriented tools may include scoring and weighting schemes, which however must be transparent (possibility to see weighting factors plus un-weighted results).

Examples:

LCA oriented (database in background):

- Athena
- BEAT

Energy and comfort oriented:

- DOE2
- Bsim2002
- EcoTect

Lighting/daylighting:

- Radiance
- Adelaine

Level 3: Whole building assessment frameworks

Try to cover all important environmental aspects in a much wider context than level 2 tools, and may include other than technical and quantitative data, such as societal, economic, and more qualitative technical considerations. Can be very extensive to carry out (much data) and may require specially trained external auditors. Usually requires use of level 2 tools for input data. Output to the user is synthesized by scoring and weighting schemes for easier understanding.

Examples:

- BREEAM
- GBTool
- ESCALE
- LEED
- MCDM-23
- EcoEffect

The IDEEB Eco-factor method is a typical level 2 tool. The whole IDEEB concept is closer to a type 3 framework, but still with a somewhat narrower scope than for instance GBTool, the main difference being IDEEBs focus on the operative phase of the building life cycle in terms of energy use and indoor climate, and not for instance resource, waste, or society impacts.

1.3.4 Adaptability

The intended users of the Eco-factor tool have different choices to make, and at different stages of the building process. To be adaptable and robust for iterative use, the tool needs to be structured in a certain way:

- Hierarchical structure. Some issues are more general than others, and may be composed of several sub-issues.
- Several “layers” of detail regarding both input and output, to adopt to increasing data flow in later design stages.
- Fixed reference frame. Possibility for adopting a stepwise refinement with increasing level of detail in data, but the same way of calculating and presenting the result.

Hierarchical structure

Some issues are more general than others, and may be composed of several sub-issues. An example is indoor climate, which is composed of individual impacts from temperatures, pollutant concentrations, etc. In the early design phase, one might typically be interested in scanning a wide range of solutions, but to receive information on a rather general level, to allow for easy comparability and rapid iterations. A solution is to have the assessment tool contain “default” values that give a direct but general result. As the design process continues, it is possible to go to more detailed levels in the structure in an iterative way, and change the default values to specific values for the considered case.

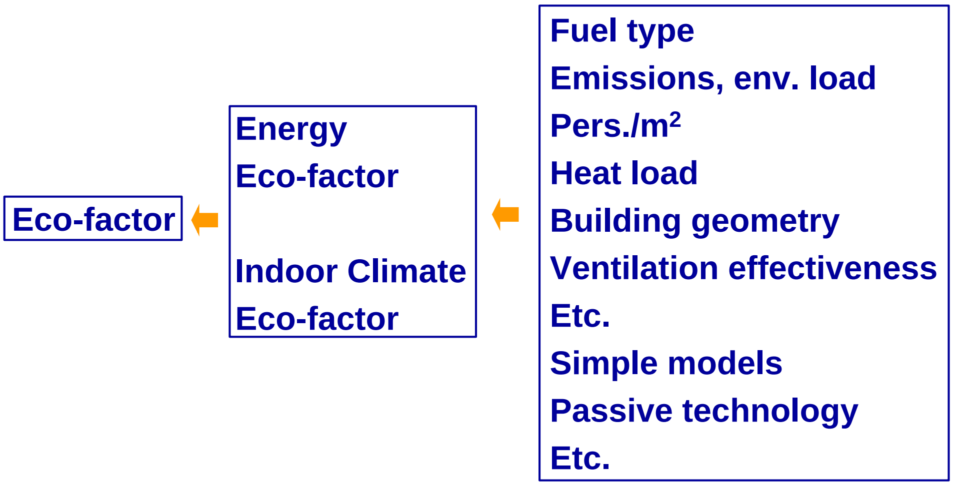

Figure 1.5 Not only just one number, but a series of numbers so that you can go back in the structure and change things (causal relation, cause and effect relationship).

Several ”layers” of details regarding both input and output

In the initial design phase the input data from the user is roughly estimated figures about energy use and basic requirements of indoor climate for different reference cases. Together with default values of e.g. indicators and weighting factors, this will give a normalized output of the Eco-factor for brief comparison of different energy solutions. In later, more detailed design, the quality of input data will increase, more precise data about energy use and estimated indoor climate. Here the user has more knowledge about the specific building and can give more input to improve the default values to be valid values for the specific case. The tool must, therefore, have several layers for more detailed information input.

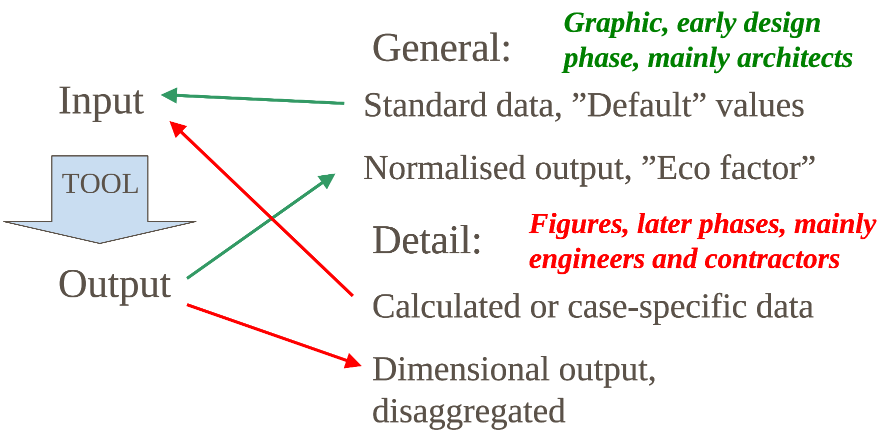

Figure 1.6 Illustration of how the Eco-factor tool may be used at two levels. General input values supplied by architects in the early design phase will give general results of the Eco-factor. Detailed input values by engineers etc. in the detailed design phase will give a resulting Eco-factor for the actual building.

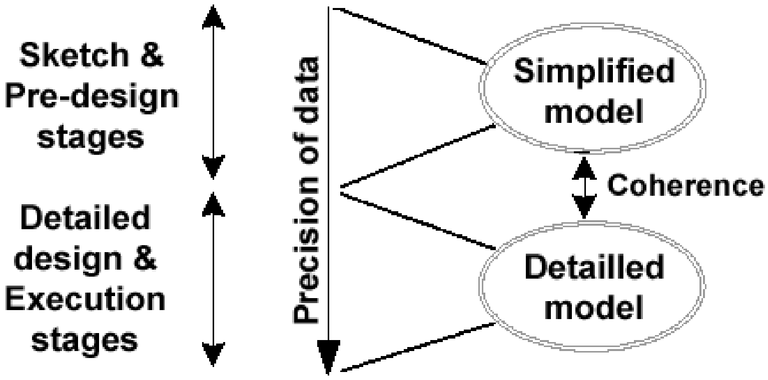

Figure 1.7 A similar concept is used in Escale, Gérard et al., 2000.

Iterative process

Adopt a stepwise refinement, and still keep the same reference frame.

Step 1: Indicators are calculated by simple calculation procedures based on some key features of the building, along with "default" values for common alternatives. Default weight factors are used.

Step 2: The same indicators can be calculated by more refined methods in later stages of the design process. Weight factors may be redefined.

This procedure is discussed in more detail later, in Chapter 4.2.

Benefits:

- Often, for a first assessment, one is satisfied with viewing “overall” indicators that are synthesised from a number of inputs.

- It is possible to aggregate subcategory further, meaning yet another “layer” of more detailed information. For instance, thermal comfort is described by a number of terms, which together add up to a total score. More detailed information about sub-indicators can help to make clear cause-effect relationships, especially in later design phases.

2. Performance Assessment

Here “performance assessment” means assessment of the quality of the building in terms of energy use and indoor climate quality. Quantitative indicators are used that can be calculated directly on the basis of the lowest possible number of key parameters in the design phase (or measured in the operative phase). This makes the method suitable for inclusion in an easy-to-use PC-tool that can assist the architect in early design stages, where rapid iterations are necessary, and where user input must be kept at a minimum.

2.1 Scoring systems

The literature survey shows several examples of scoring systems of different types. In all cases, an assessment tool needs to judge the quality of a building according to some pre-defined standards and issues. This gives rise to a need for *indicators* and *benchmarks*, which are described in more detail below.

2.1.1 Indicators and Benchmarks

IEA ECBCS Annex 31 makes the following comments on different types of indicators:
Tool designers are faced with a difficult choice when selecting indicators, due to the diversity of possibilities, the complexity of some phenomena involved, and the lack of precedents. Usually the decision must reflect the availability of data, and the familiarity of indicators to users. Also it is possible to choose indicators that reflect multiple objectives, and therefore provide especially efficient evaluations.

Different types of indicators serve different purposes. Indicators can be:

- **Quantitative** (e.g. water consumption in m^3/year), or
- **Qualitative** (e.g. type of heating terminal units). It should be noted that qualitative does not necessarily mean subjective.

Indicators can be:

- **Results** oriented (e.g. Illuminance levels), or
- **Means** oriented (e.g. type of solar protection installed to avoid sun glare).
  Means oriented indicators can be either
  - **Operational** (e.g. technical solutions) or
  - **Management** (e.g. organisational rules).

Indicators can be:

- **Extensive**, coming from the sum of the “additive” values (e.g. energy consumption in kWh/year), or
- **Intensive**, coming from a behavioural model (e.g. the operative temperature of a room). With intensive indicators it is necessary to decide on which rooms the "assessment has to be applied, and then to carry out an aggregation.”

Indicators for the Eco-factor method

The IDEEB Eco-factor method is using quantitative and results oriented indicators, where extensive indicators are used for Energy use and intensive indicators are used for Indoor climate.

Energy use (Extensive indicator):

- Specific energy use of each energy source (kWh/(year, m^2))

Extensive indicator – since it is possible and meaningful to accumulate figures for energy use. The environmental impact from the energy production is related to the total amount of fuel consumption over a period of time, and not on how quickly the fuel is used at some specific point in time.

Indoor Climate (Intensive indicators):

- Thermal comfort: PPD, Predicted Percentage of Dissatisfied; PD, Percentage Dissatisfied; DR, Draught Rating.
- IAQ: presence of pollutants, ventilation effectiveness => PD, Percentage Dissatisfied.

Intensive indicator: It is not in the same manner as for energy use possible to use cumulative figures. It is also more interesting to know how indoor climate is at specific points in time, e.g. cases for summer/winter, day/night, morning/afternoon, etc. This is especially the case, since a building will be perceived as uncomfortable, even if the occupants are in fact only truly dissatisfied part of the time.

Benchmarks

The scale for each indicator must by necessity be based on at least two fixed points. These could typically be chosen as:

- an “average” level, this could for instance be represented by national standards and regulations (as used in GBTool and others), and
- an “upper” level, represented by either
  - data from existing buildings (“best practice”) or
  - theoretical considerations (“best possible”).

It is also possible to include more than two benchmarks, for instance both “best practice” and “best possible”. Less than standard benchmarks can be defined. This has been the case with the scoring functions in GBTool and in ESCALE.

2.1.2 Classification

Two examples of classification are by “checklist” and by “score function” which both are shown below to illustrate the difference between qualitative and quantitative classification.

Checklist

Checklists are mainly useful for qualitative assessment. The result of the evaluation is given by quality classification factors of the building in each impact sub-category in accordance with pre-defined quality standards. The impact sub-categories can be based on design initiatives (”it is possible to take initiatives in these fields – how many issues are addressed satisfactory?”). Examples: BREEAM, LEED and MDCM-23.

Table 2.1 Example of value tables for qualitative criteria from MDCDM-23 (Balcomb et al., 2001). In this case the adaptability of the building evaluated in terms of being able to accommodate different types of clients with as little rebuilding as possible.

Score	Judgement	Adaptability
10	excellent	Different clients without change
9	good to excellent	Different clients by moving adjustable partitions
8	good	Different clients by rebuilding non-load bearing partitions
7	fair to good	Different clients by rebuilding non-load bearing partitions
6	fair	Different clients by rebuilding mostly non-load bearing partitions
5	borderline fair	Different clients by rebuilding all load bearing partitions
4	marginally acceptable	Not adaptable to different clients

Score function

Score functions are based on estimation of quantitative factors. This classification is used for the IDEEB Eco-factor and similar classifications are used for e.g. GBTool, ESCALE, Dutch environmental index system and MCDM-23.

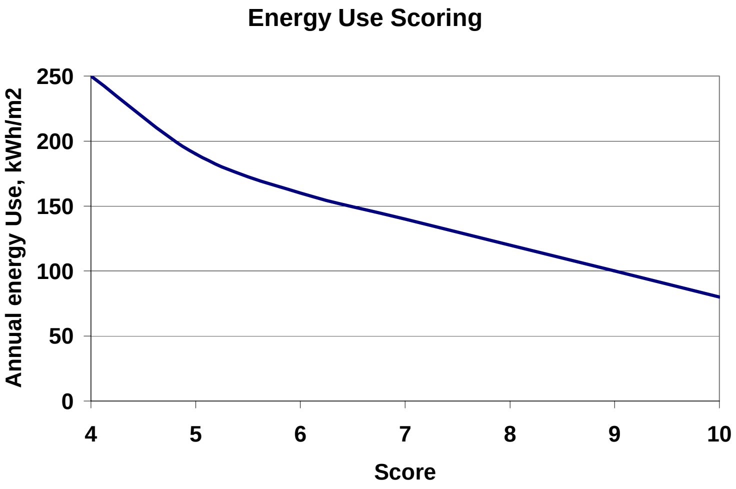

Figure 2.1 Example of score function for energy use from MDCDM-23 (Balcomb et al., 2001).

One can use a number of classes or benchmarks to define the score function. It is then possible to define a (mathematical) function connecting the fixed points, which is useful for a calculation tool. It could be possible to score negative points (as for example by GBTool and Escale), or to exceed the "best possible" rating, but it is also possible to set maximum and minimum boundaries as in the example.

The IDEEB Eco-factor method has a fixed scale from 0-100% with linear score functions, since this is easy to understand intuitively. The choice of indicators and benchmarks will be explained in the following chapters.

2.2 Energy

The Energy Eco-factor has one subcategory, emission impact, which describes the environmental load caused by emissions to air.
Energy Eco factor:

- Emission impact
    - Specific energy use for each energy source (kWh/(year, m^2))

The emission impact is calculated for each energy source by considering:

- Boundary conditions for energy use
    - Operation phase
    - Annual energy use for operation
    - Treated area

- Emission impact from energy sources
    - The life cycle of the energy source
    - Impacts due to emissions to air
    - Established environmental assessment methods

The main purpose of the Eco-factor method is to be used for assessment between alternative choices of technical energy-solutions in the design of European office buildings and to optimise the use of different energy sources in the operation phase. In order to identify where measures will have good opportunities to increase the Eco-factor score, the energy use can be divided into different functions to identify their contributions to the score.

In 1999 the Swedish Parliament adopted fifteen environmentally quality objectives in order to enlighten the importance of reducing particularly these impacts. The first objective is “reducing climate impact” (global warming), the second “clean air” regarding photochemical ozone formation and fine particles, the third “natural acidification only” and the seventh “zero eutrophication” (Environmental Objectives Council, 2004). These objectives are in accordance with the environmental impacts that are caused by the major emissions from energy use, except use of nuclear power, and are considered in the Eco-factor. Besides environmental impact of emissions to air energy use will influence environmental impacts as use of natural resources, radiation and production of radioactive waste. The main environmental impact from nuclear power is enlightened by the sixth environmentally quality objective “a safe radiation environment”.

Use of natural resources, radiation and production of radioactive waste, together with other aspects as advantages to use waste heat from a near by factory or to produce heat from combustion of waste instead of deposit, will not be reflected directly into the emission impact. Consideration of these aspects in the assessment, besides calculation of the Energy Eco-factor, can be facilitated by identifying:

- the use of different categories of energy sources
- a low-priority factor

The low-priority factor is meant to describe how important other aspects, than environmental impacts due to emissions of air, should be for making a difference in the assessment.

Market forces may indirectly cause a consideration of the environmental impact due to use of natural resources.

2.2.1 Boundary conditions

To do a proper assessment between different technical energy solutions it is important that the comparison is made for the same boundary conditions. A comparison of different energy-solutions performance for a specific building should use the annual energy input for the same year and operation as well as the same defined area.

The energy use is calculated in the design phase either by simple methods or by detailed energy simulations, this is described more thoroughly in Brohus et al., 2004. In the operation phase the Eco-factor method is primarily aimed to optimise the use of different energy sources by measurements and control with the control system. The calculated or measured energy uses from all energy sources are used in order to calculate an Eco-factor for the building and thereby declare the building’s performance.

In order to define a fixed standard for the Energy Eco-factor, with a reference frame that is suitable for EU offices, the specific energy input for the buildings is defined for the following boundary conditions:

- Operation phase
- Annual energy use for operation
- Treated area

This fixed standard for the Energy Eco-factor could also be used to compare a building's performance with other regional, national or European buildings. This also requires additional well-defined boundary conditions. Comparison of energy performance of buildings from different years requires a correction since the measured or calculated year might have been colder or warmer than the year for the compared building. The correction can be done to a normal year by using degreeday-correction.

Operation phase

Some detailed lifecycle investigations have been made during the last years; for typical and low energy family houses in Norway (Németh Whinter, 1998), for a typical three story office building in Vancouver and Toronto, Canada (Cole and Kernan, 1996), for typical multi-family houses in Sweden (Adalberth, 1999), for low-energy family houses in Sweden (Adalberth, 2000), for a typical single family house at different places in USA (Van Geem et al., 2001) and for typical residential buildings, schools and offices in Sweden (Ståhl, 2002). These investigations have showed that the energy use for operation counts for the major part of the total lifecycle energy use and is between 80 and 95%. Less than 20% is used for manufacturing of building materials, transportation of materials, building, maintenance and demolition. These conditions might of course be different in other climates and in other building cultures, for example for south European conditions.

However, with measures to decrease the energy use in the operation phase, the energy use for building, maintenance and demolition will become more important. For example, a 50% reduction of the operation energy use will give a decrease of the operation energy part from 80 to70% of the total lifecycle energy for the investigated offices in Canada (Cole and Kernan, 1996). Nemeth Whinter, 1998, shows that a house with super insulation and a heat pump etc can reduce the operation energy part to 58% of the total lifecycle energy.

Efforts to decrease the environmental impact from energy used in the operation phase will therefore have high effect. Indicators for the Energy Eco-factor are, therefore, based on operation energy use. However, it will be important to include the buildings total lifecycle in the future, as discussed in Chapter 1.2, when the operation energy use will –hopefully- decrease.

Annual energy use for operation

The complete energy system of the building is considered with its total yearly supplied energy. For uses that only can be performed with electricity all energy input is considered. This means electrical appliances for ventilation, lighting, office equipment and other electricity. While electricity use for process, e.g. catering or computer rooms, which is not in direct connection with the office part of the building, is not considered. It is important to consider all electricity appliances since the heat that generates from the appliances will affect the consumption of heating and cooling energy supply. This will encourage choosing low-power appliances when the energy source for heating is more beneficial than electricity as well as rewarding the double effect of both reduction in electricity use and cooling need.

For energy supply of heating and cooling, which can be performed with several different energy sources, also energy use for tap water is included. Tap water is included here even though the energy use for tap water is separated from the building's other energy performance. The primary reason is that there are several possibilities to improve the environmental performance by choosing the right energy sources for the tap water production. Other reasons are that it can be difficult to separate the energy supply for tap water from heating in the operation phase and that the tap water is just a small part of the total heating energy supply for offices, usually between 2-7% (Nilsson et al. 1996).

Treated area

In the Eco-factor method the buildings area is defined as treated useable area, the building's inside area that is heated or cooled. This is in accordance with a Swedish investigation about ratio of energy use in buildings by the National Board of Housing, Building and Planning (Johansson and Storm, 2001). In some cases it can also be relevant to compare energy use per person since many occupants on a small area require high energy use for cooling and a high air exchange rate.

2.2.2 Emission impact

The emission impact part of the Energy Eco-factor describes the environmental impact from the building due to emissions from the annual energy supply of each energy source and is based on:

- The life cycle of the energy source.
- Impacts due to emissions to air.
- Established environmental assessment methods.

The life cycle of the energy source

The environmental impact will not only be dependent on the energy source but also on that energy source complete life cycle (extraction, production, transportation and combustion). The environmental impact of the greenhouse effect for extraction, production and transportation of wood is, for example, over 40% of the total life cycle emissions from wood combustion (Uppenberg et al., 1999).

Impact due to emissions to air

The emissions considered are emissions to air that will influence the environment by impact on global warming, acidification, photochemical ozone formation, eutrophication, and emission of fine particles. The emissions are CO_2, SO_x, NO_x, CH_4, CO, N_2O, NmVOC (non-methane volatile organic compounds), NH_3 and particles. The first four categories are in accordance with recommendations in the Environmental Performance Declarations (Swedish Environmental Council, 2000). Resent studies of the last category, fine particles, have showed that fine particles penetrates directly into the lungs, causing allergies, cardiovascular and respiratory diseases and cancer and must therefore also be considered (Tiuri, 1998). These are the mainly emissions to air due to energy use. After decision of the phasing out CFC working fluids in heat pumps and air conditioning (Montreal Protocol, 1994) are ozone depletion emissions becoming more and more of rare occurrence and they are not considered here.

Established environmental assessment methods

Today several environmental assessment methods are used in the world in order to give environmental aspects of different applications. These are built up for example to give environmental priority strategies in product development, e.g. EPS (Steen, 1999 and Ryding et al. 1998) or Eco-indicator 99 (Goedkoop and Spriensma, 2000). Some of them are considering the same substances as in the Eco-factor method and have defined assessment index for each substance. The index describes the magnitude of the environmental effect caused by the substance. In most methods, the index is set by considering the environmental impacts by effects on global warming, acidification etc. and its related impact on human health and the ecosystem's quality.

2.2.3 Definition of the Energy Eco-factor

The definition of the transform equation for the Energy Eco-factor is based on specific indicators for the energy sources and annual net energy input. This equation will be specific for each established environmental assessment method since each method has unique assessment indexes and therefore will get different indicators. The equation for each established environmental assessment method is determined with the same procedure by using two fixed well-defined points. Because of the focus in IDEEB on making a tool suitable for use in Europe, the fixed standard should preferably be chosen so that the reference frame is suitable for European offices.

The equations have the following defined requirements:

- The Energy Eco-factor should be an easily understandable comparison from 0 – 100%.

- An Energy Eco-factor of 100% should be the same as "no energy related emissions". It is a description of "best possible" practice, which has no emissions due to energy use.

- An Energy Eco-factor of 25% should represent the emission impact of an average European office. This point is chosen in order to get a reasonable reference frame where offices that have an emission impact less than average will get an Eco-factor larger than 25%.

The two fixed points are chosen in order to give a reasonable, meaningful, common reference frame. A reference frame where the Energy Eco-factor will not be consistently either very high or very low, and design changes can be verified. The emission impact of an average European office is defined as 25% in order to get a broad scale (25 –100%) for offices that have made improvements compared to the average. An Energy Eco-factor between 0-25% shows that the emission impact is higher than the European average but that it still can be better than average in specific areas or for specific purposes due to dependence on outdoor climate conditions, building use, availability of energy sources etc. The following equation describes the basic definitions for calculating the Energy Eco-factor for different established environmental assessment methods:

$$\varepsilon_E = 100 - \frac{75 \cdot I}{I_{25\%}}$$ **Equation 1**

for $I < 0$ are $\varepsilon_E = 100$
for $I > 1.333 \cdot I_{25\%}$ are $\varepsilon_E = 0$

where:

ε_E = Energy Eco-factor (0-100%)

I = indicator for the emission impact (Indicator unit/(m^2, year))

$I_{25\%}$ = indicator for the emission impact for an average European office (Indicator unit/(m^2, year))

The indicator for the emission impact is specific for each established environmental assessment method.

A high score of the Energy Eco-factor means that the building is energy efficient or/and are using the right energy sources. The Energy Eco-factor cannot be above 100%. A low score shows that the building is using unnecessarily energy or/and is using energy sources that should be avoided. The method does not consider scores below 0%.

A new or retrofitting design of a building that has an emission impact that is considerable lower than the fixed point for the European average is not acceptable and will therefore not reach a score in the Energy Eco-factor method. It should be possible by an intelligently design to reach a score for all buildings independent on limitations due to outdoor climate conditions, building use, building location, building original design, availability of energy sources etc.

A score above 25% indicates that the office is better than a typical European office. However, it does not say that the building performs well while considering its specific outdoor climate conditions, building use, building location, availability of low-emission-impact energy sources etc. By introducing other standard offices for typical or best practice within the same building category to the scale, it can be evaluated if the considered office has a reasonable Eco-factor or if it easily could be improved.

2.2.4 Definition of average European office

The annual average energy use in a European office has been defined based on figures collected in a survey of EU member states about energy consumption in the service sector (European Communities, 2002). In the survey 13 member states were participating but all countries has not been able to give figures for energy consumption per floor area, which is needed for the Eco-factor method. Table 2.2 shows the given energy consumptions per floor area for offices and administration buildings. The data have been collected for different reference years between 1996 and 1999. The average values for energy consumption of space heating and hot water and for total electricity consumption have been used to define the average European office.

The survey of the 13 EU Member states (European Communities, 2002) presents besides total consumption of energy for space heating and hot water in offices and administration buildings, the energy consumption divided into types of supplied fuels. The energy sources are divided into heating oil, natural gas, electricity, LPG gas, solid fuels, district heating and others where the main energy sources for space heating and hot water are natural gas with 47% and heating oil with 25% of the total energy supply, while the other 28% are divided between several other energy sources. By only considering the two dominating energy sources (excluding the “other” energy sources) will give a share between natural gas and heating oil of 65% respectively 35%. Energy sources for space heating and hot water in the average European office have therefore been defined as heating oil and natural gas with the share that they are represented with in Europe, 35% heating oil and 65% natural gas.

Table 2.2 Energy consumption for offices and administration buildings in EU member states (European Communities, 2002).

Country	**Reference year**	**Space heating and hot water** kWh/(m^2, year)	**Air-conditioning, cooling and ventilation**[1] kWh/(m^2, year)	**Lighting** kWh/(m^2, year)	**Electrical appliances**[2] kWh/(m^2, year)	**Total electricity consumption** kWh/(m^2, year)
Germany	1997	253.1	2.8	32	45.4	80.2
Greece	1998	-	17	28	67.5	112.5
Finland	1998	170.3	39	30	55	124
France	1996	193.9	72	43	46	161
Netherlands	1999	102.8	-	-	-	-
Spain	1998	53.6	45	71	49	165
Sweden	1997	130	-	-	-	-
Average		**150.6**	35,2	40,8	52,6	**128.5**

[1] Energy consumption for air-conditioning, cooling and ventilation is by 96% supplied by electricity.

[2] Energy consumption for electrical appliances was not given directly in consumption by square meter in European Communities, 2002, and have therefore been calculated from the same floor area as for energy consumption of lighting.

Energy sources for electricity use for the average European office are defined as EU-average electricity according to Table 2.3 (IEA, 2002).

Table 2.3 Electricity supply in EU 2001 (IEA, 2002).

Production	**Share (%)**
Combustible Fuels	51
Nuclear	34
Hydro	14.5
Other/Geothermal	0.5

The average European office is defined with specific energy input for each energy source according to Table 2.4.

Table 2.4 Definition of average European office

	Annual energy input kWh/(m^2, year)	**Energy sources**
Space heating and hot water	150.6	65.2% natural gas 34.8% heating oil
Total Electricity use	128.5	EU average 2001 (Table 2.3)

2.2.5 Emission impact Indicator

The Indicator for the emission impact is specific for each environmental assessment method. The methods that are considered here are all established and the Indicator is calculated according to the following base equations:

$$I = \frac{\sum_{i}^{n} (k_i \cdot Q_i)}{A} \qquad \textbf{Equation 2}$$

where:

I = specific indicator for the emission impact (Indicator unit/(m^2, year))
k = environmental impact factor (Indicator unit/kWh)
Q = annual net energy input (kWh/year)
A = treated useable area (m^2)
i = energy source

and

$$k_i = \sum_{j}^{n} (e_j \cdot index_j) \qquad \textbf{Equation 3}$$

where:

k = environmental impact factor (Indicator unit/kWh)
e = emission (kg/kWh)
$index$ = assessment index (Indicator unit/kg)
j = emission substance
i = energy source

Each established environmental assessment methods have its own Indicator system with its own Indicator unit for assessment of the emission impact. The Indicator unit can for example be ELU (Environmental Load Unit) or kg CO_2-eqvivalents.

The assessment index, *index*, is specific for each emission substance and the environmental impact factor, *k*, is specific for each energy source and both are specific for each environmental assessment method or for impact on an environmental effect.

Table 2.5 Examples of assessment indexes, *index*, for the environmental assessment methods EPS (Steen, 1999 and Ryding et al. 1998) and Eco-indicator 99 (Goedkoop and Spriensma, 2000) as well as examples of assessment indexes for impact on the Greenhouse effect and Acidification (Swedish Environmental Council, 2000)

Emission	**EPS** (ELU/kg)	**Eco-indicator 99** (Pt/kg)	**Greenhouse Effect** (kg CO_2-eqvivalents/kg)	**Acidification** (mole H^+/kg)
CH_4	2.72	0.114332	21	0
N_2O	38.3	1.79	310	0
CO	0.331	0.00332	0	0
CO_2	0.108	0.00545	1	0
NH_3	2.90	3.42	0	58,7
NmVOC	2.0	0.05	0	0
NO_x	2.13	2.745	0	21,7
SO_x	3.27	1.5012	0	31,2
Particles	36.0	9.74	0	0

The environmental assessment method EPS (Environmental Priority Strategies) express the additional environmental load that a resource use, a pollutant, a material, a process or an activity will cause during its complete lifecycle (Steen, 1999 and Ryding et al. 1998). The value of the environmental index is based on the influence of one or several of the five protection objectives: biological diversity, human health, the ecosystem’s reproducibility, natural resources and aesthetic values. The impact of the protection objectives is valuated after how much money the inhabitants in the OECD-countries are willing to pay in order to restore the protection objectives to their reference condition (the condition in 1990). In other words is the valuation based on the inhabitants in the OECD-countries willingness to pay in order to avoid an environmental change. The environmental load is expressed in ELU (Environmental Load Unit).

Eco-indicator 99 is mainly based on lifecycle analysis that is supplemented with a concept of so called eco-indicators (Goedkoop and Spriensma, 2000). The eco-indicators are an aggregated measure on the environmental load that is raised at manufacturing of for example a material or from a process. The result from the inventory analysis is transformed to damage factors with three damage categories; human health, ecosystem quality and resources. The three damage categories have different units and is therefore normalized and thereafter weighted into one single indicator. The weighting factors is defined by a written panel procedure among a Swiss LCA interest and is thereby subjective and can not be considered to be representative for the average European. The standard Eco-indicator value can be regarded as dimensionless figures. As a name the Eco-indicator point (Pt) is used. The value of 1 point is representative for one thousandth of the yearly environmental load from one average European inhabitant.

The Greenhouse effect is expressed in kg CO_2-eqvivalents and acidification in molar of H^+ (Swedish Environmental Council, 2000). These environmental effects are based on more or less objective evaluations while environmental assessment methods that weights different environmental impacts together are based on subjective valuations.

Emission impact indicator for average European office

In order to calculate the emission impact indicator ($I_{25\%}$) for the average European office the environmental impact factor, *k*, for heat produced by combustion of oil and natural gas as well as for EU average electricity must first be calculated according to Equation 3.

First the emissions, *e*, for each energy source is calculated by using a free to use Internet tool for environmental assessment of heating systems (EFFem, 2004). The Internet tool requires input data of fuel shares and is based on a method described by Wahlström et al., 2000 and 2002, which also give references to used lifecycle inventories for the emissions. Emissions from electricity are calculated for average power plants in Sweden and weighted according to the shares in Table 2.3. Emissions from heat production with fuel oil 1 and natural gas are calculated according to Wahlström et al., 2000 and 2002, and are for average Swedish dwellings and small district heating plants (less than 50 MW and 82 % efficiency). The emissions are given in Table 2.6.

Table 2.6 Emissions, *e*, from supplied electricity in EU and heat produced by combustion of oil and natural gas in dwellings and small district heating plants (Wahlström et al., 2000 and 2002).

Emission	**EU average production of electricity** (mg/kWh)	**Heat produced by natural gas combustion** (mg/kWh)	**Heat produced by oil combustion** (mg/kWh)
CO_2	268 700	250 300	344 600
N_2O	1.8	2.4	2.3
CO	61	55	142
CH_4	29	12	14
NH_3	2.1	0	2.2
NMVOC	23	11	202
NO_x	411	96	395
SO_x	624	1	169
Particles	56	0	122

The emissions, *e* (Table 2.5), together with the assessment index, *index* (Table 2.4), will give the environmental impact factor, *k*, for each energy source according to Equation 3. The results are given in Table 2.7.

Table 2.7 Environmental impact factors, *k*, for different energy sources and different environmental assessment methods.

Environmental assessment method	Unit of environmental impact factor	EU average electricity, 2001	Heat produced by natural gas combustion	Heat produced by oil combustion
EPS	mELU/kWh	34.2	27.4	43.6
Eco-indicator 99	mPt/kWh	4.1	1.6	4.4
Greenhouse Effect	g CO_2-qvivalents/kWh	269.3	250.6	344.9
Acidification	mmole H^+/kWh	28.5	2.1	14.0

The emission impact indicator ($I_{25\%}$) for the average European office is calculated with the environmental impact factor, *k* (Table 2.7), and the definition of an average EU office (Table 2.4) according to Equation 2. The results are given in Table 2.8.

Table 2.8 Emission impact indicator for an average European office, ($I_{25\%}$), for different environmental assessment methods

Environmental assessment method	Unit of environmental impact indicator	$I_{25\%}$
EPS	mELU/(m^2, year)	9368
Eco-indicator 99	mPt/(m^2, year)	918
Greenhouse Effect	kg CO_2-qvivalents/(m^2, year)	77.3
Acidification	mole H^+/(m^2, year)	4.6

2.2.6 Examples of Energy Eco-factors for different offices

Five cases for different offices have been studied as examples on how the Energy Eco-factor works. The first two defined cases (Case 1-2) in Table 2.10 are representing annual energy use for a typical air-conditioned standard office and a typical natural ventilated open plan office in United Kingdom (EEBPP, 2000) while the third and forth Case represents good practise of an air-conditioned standard office and a good practise natural ventilated cellular office in United Kingdom (EEBPP, 2000). The electricity use for cooling, fans, pumps, controls, humidification, lighting, office equipment and other electricity is considered and it is defined as EU-average according to IEA, 2002. The heating energy is for both heating of tap water and space heating and is defined as produced by combustion of natural gas in Case 1 and 2, which is the most common energy source for this purpose in office in United Kingdom (European Communities, 2002). In Case 3 and 4 are the heating energy supplied by district heating that is produced with biofuel.

Case 5 represent a target that has been defined in a Swedish dialog between 20 companies representing the building industry, three municipalities and the Environmental Advisory

Council. A common vision with strategies is presented with a defined target on all energy input for heating and electricity needed in offices 2025 (EAC, 2000). The vision includes strategies and striving for sustainable buildings and the heating source has therefore been chosen to be district heating that is produced with biofuel and the electricity is supposed to be environmentally labelled electricity.

Emissions from environmentally labelled electricity and district heating produced with biofuel are calculated according to Wahlström et al., 2000 and 2002, by using EFFem, 2004 (a free to use Internet tool). The used emissions are given in Table 2.9.

Table 2.9 Emissions, *e*, environmentally labelled electricity and heat supplied by district heating produced with combustion of biofuel (Wahlström et al., 2000 and 2002).

Emission	**Environmentally labelled electricity** (mg/kWh)	**District heating produced with biofuel** (mg/kWh)
CO_2	5438	8530
N_2O	0	12.5
CO	9.6	394
CH_4	6	19
NH_3	0	7.7
NMVOC	1.5	94
NO_x	7.5	351
SO_x	2.2	82
Particles	1.1	66

Table 2.10 Different cases for energy use in offices.

Case no:	**Description**	**Electricity input** kWh/(m^2, year)	**Heating input** kWh/(m^2, year)	**Energy source for electricity**	**Energy source for heating**
1	Typical air-conditioned standard office in UK	202	178	EU average	Natural gas
2	Typical natural ventilated open plan office in UK	151	80	EU average	Natural gas
3	Good practise air-conditioned standard office in UK	109	97	EU average	District heating produced with biofuel
4	Good practise natural ventilated cellular office in UK	79	31	EU average	District heating produced with biofuel
5	Swedish energy target for offices in 2025	40	30	Environmental labelled electricity	District heating produced with biofuel

The Energy Eco-factors (ε_E) for the five cases are calculated with Equations 1-3 and $I_{25\%}$ given in Table 2.8. The results are shown in Figures 2.2 – 2.5.

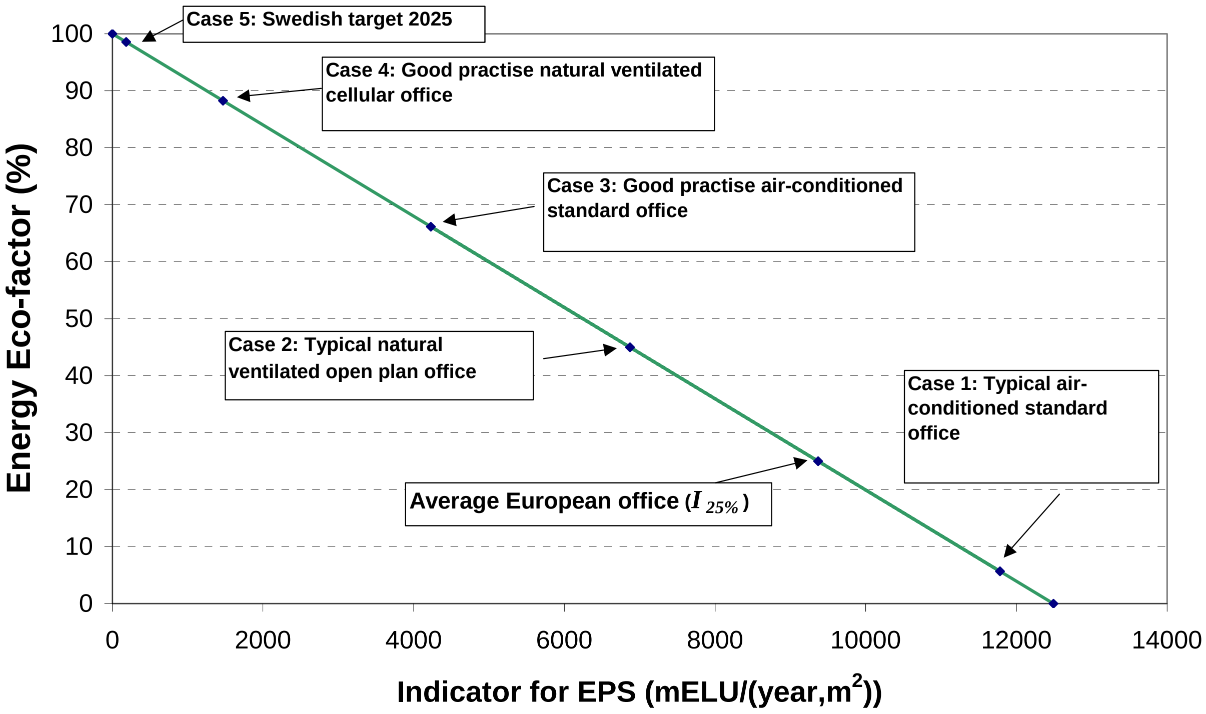

Figure 2.2 Score function for the Energy Eco-factor from specific indicators in the EPS method.

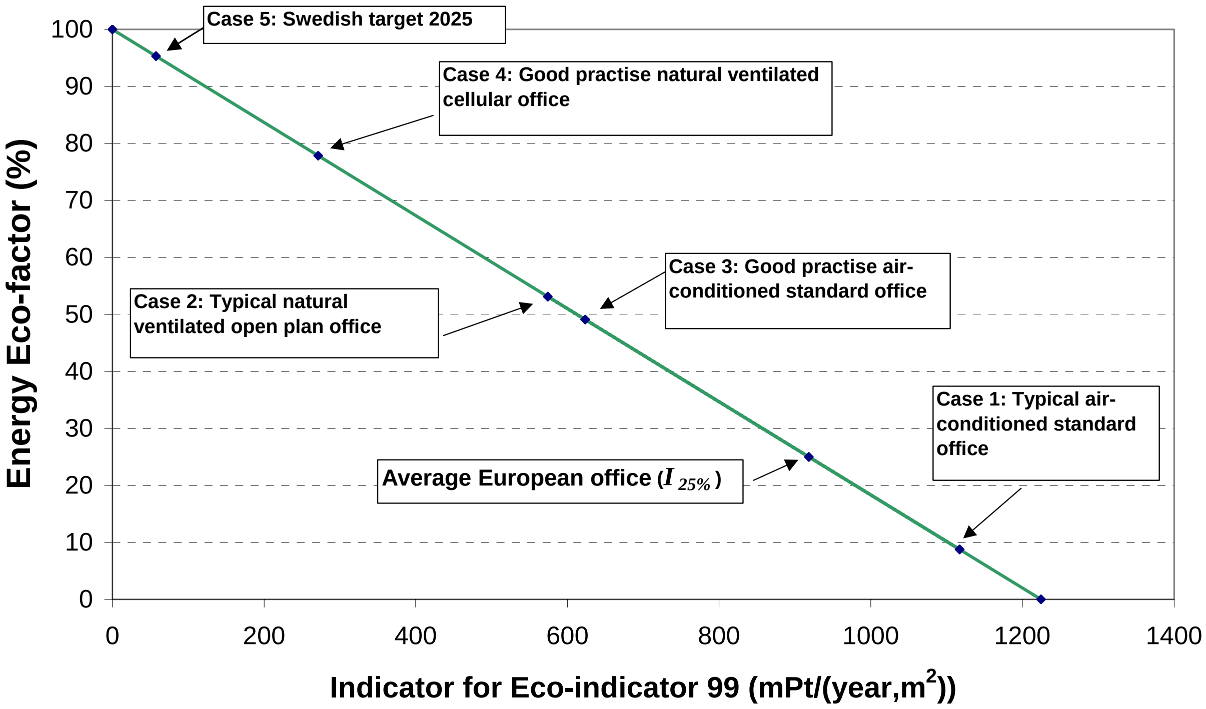

Figure 2.3 Score function for the Energy Eco-factor from specific indicators in the Eco-indicator 99 method.

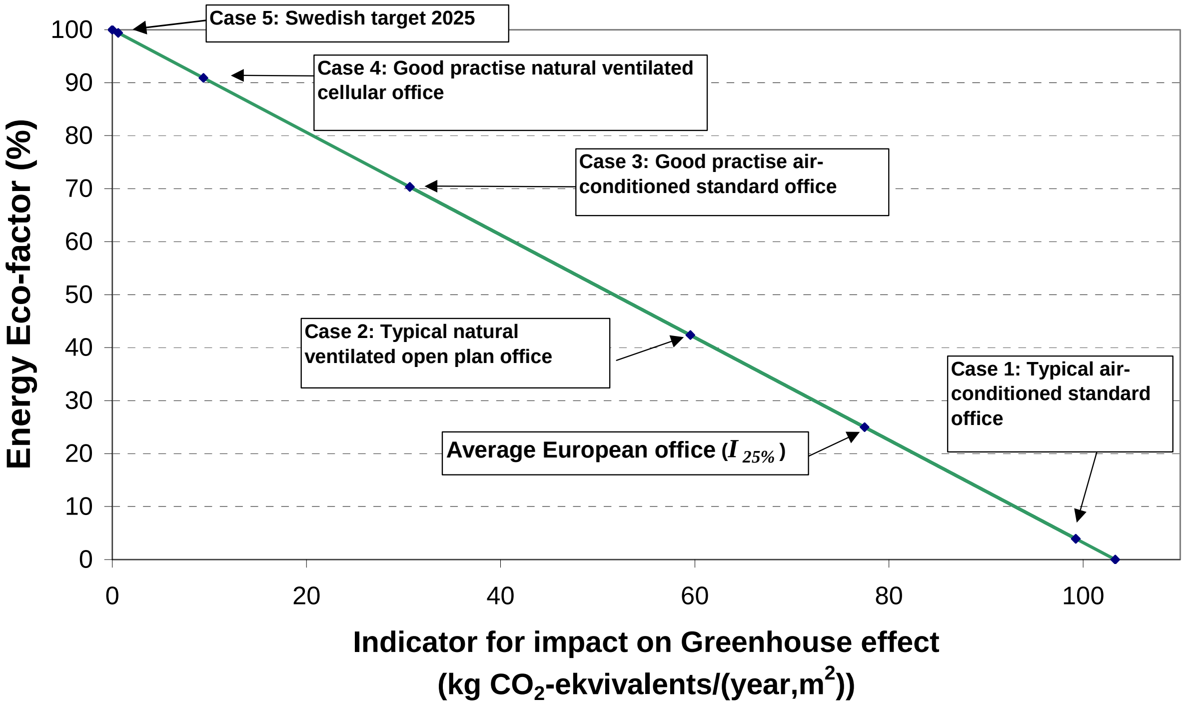

Figure 2.4 Score function for the Energy Eco-factor from specific indicators for impact on the greenhouse effect.

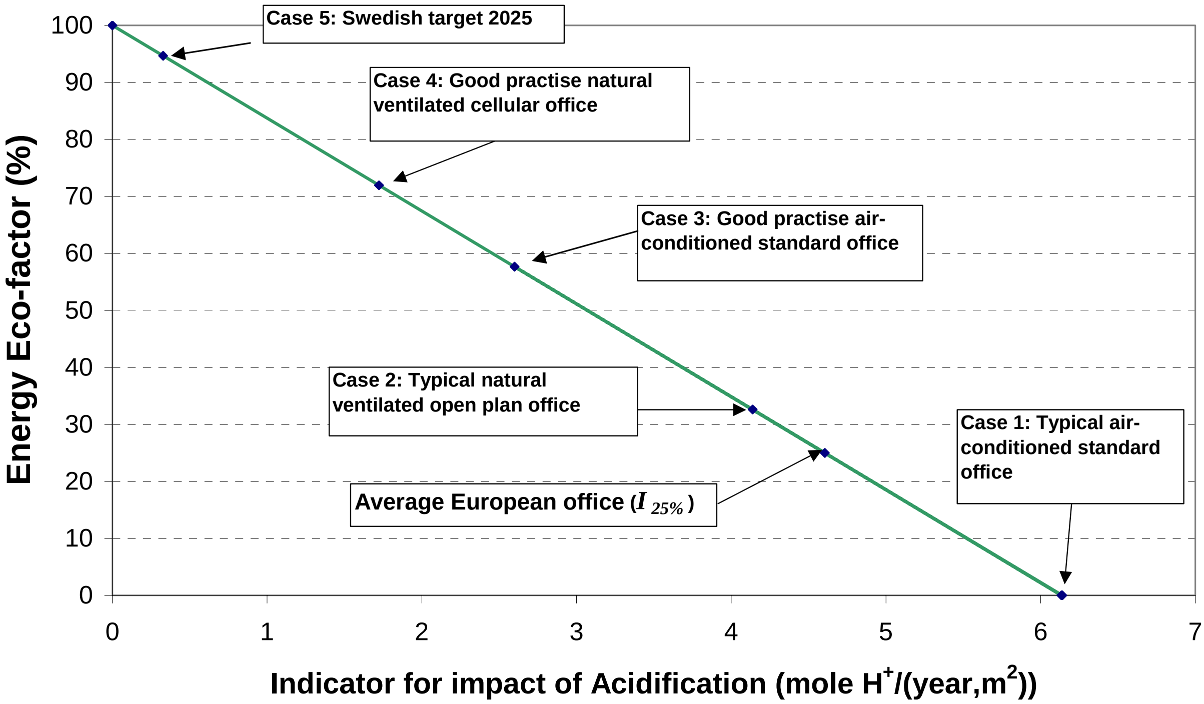

Figure 2.5 Score function for the Energy Eco-factor from specific indicators for impact on acidification.

2.2.7 Aggregation of data from different energy uses and sources

Division into categories by energy use functions and by energy sources may be used to facilitate the assessment.

Energy use

By distinguish the Eco-factor score contribution from different functions it is beneficial to do a division of the net energy with its energy sources into different use functions before collecting it into one score. This will facilitate to identify which part of the design that is causing the result and where it might be advantageous to do energy measures.

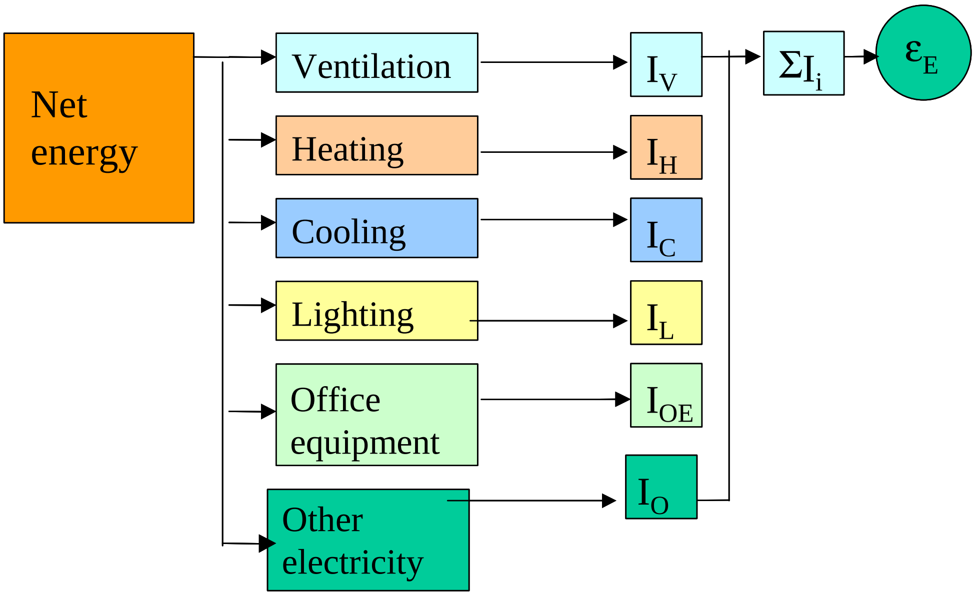

Figure 2.6 Division of net energy input in different functions in order to identify their different contributions to the Eco-factor score.

Energy source

To preserve nature’s sustainability, the natural resource depletion must be limited. It is therefore important to choose energy sources that have short-term effect on the resource availability. It is also important to avoid energy sources with environmental impacts of radiation and radioactive waste. Other aspects as advantages to use waste heat from a near by factory or to produce heat from combustion of waste instead of deposit are also important to consider when choosing energy sources. Aspects of the use of energy resources can be assessed, at comparison of two alternative technical energy solutions, by dividing the net energy input into categories of:

- renewable energy sources
- fossil fuel
- waste
- waste heat
- nuclear power

Use of natural resources will not be directly reflected into the Energy Eco-factor but it is an important consideration when choosing energy sources. However, non-renewable energy sources, except nuclear power, are already of less priority in the Energy Eco-factor since they have high carbon dioxide emissions. Endless resources as solar energy or wind power have low emissions and will therefore be preferential in the Eco-factor. This is the same situation for waste heat that neither has any emissions but here aspects as availability and alternative use must be considered. Bio fuels that are renewable energy sources will get high scores for the Energy Eco-factor since their carbon dioxide emissions at combustion are considered as zero due to that the emissions are a part in the natural carbon dioxide circulation. Nuclear power will get high priority in the Energy Eco-factor due to its low emissions even though it has high environmental impacts of radiation and radioactive waste. These disadvantages will not be directly reflected into the Energy Eco-factor but can be enlighten in the assessment by division into categories. (Another way of enlighten nuclear power in the assessment is to use a low-priority factor, see Chapter2.2.8.)

The division into categories may be used to facilitate the assessment, for example when a country or a company have political decisions that nuclear power should be avoided. Other aspects can be that a company has a policy that they should increase their use of renewable energy sources or that they should prefer use of waste heat from a close factory. A municipality might have a policy that they should combust their domestic waste since it is no possibilities for a dump within the municipality.

Renewable energies

The energy sources in this category are endless or can be recovered in a short term of less than 100 years. Endless energy sources can be solar or wind energy while renewable energy sources can be bio fuels. These sources are beneficial to use.

Fossil fuels

The energy sources in this category require considerably longer time than 100 years to recover, if they will recover at all. Examples of fossil fuels are oil, natural gas, coal etc. Also other non-renewable energy sources will belong here, as for example peat. These sources should be avoided while considering environmental impact due to use of natural resources.

Waste

Energy can be produced by combustion of waste. Instead of increasing the waste deposits, that are an environmental impact in itself, it can be beneficial to use waste as fuel even if the emissions might be high. Examples of waste are domestic waste, rubber from tires etc.

Waste heat

Also waste heat is considered as beneficial to use, since these energy sources otherwise will be lost. However, this requires extra consideration so that the source for the waste heat will not be eliminated, for example if a factory closes down. If the factory is instable, the energy source needs to have an alternative solution in the future. Examples of waste heat are sewage from a municipality, or hot streams from industry. Sources as high quality heat from an industry that can be used to produce electricity is not considered as waste heat. These energy sources should be regarded as products from the industry and the lifecycle inventory should be based on all emissions and products from the industry.

Nuclear power

Nuclear power is a non-renewable energy source that has low emissions to air even though the complete lifecycle of the energy source is considered. Nuclear power will, on the other hand, have vital environmental impacts in case of nuclear power plant accidents. It also creates radioactive waste that requires safe terminal storages, and these storages will be left for the next generations to take care of. The environmental impact from nuclear power is therefore difficult to judge. A way of enlighten assessment of nuclear power is described in the next chapter.

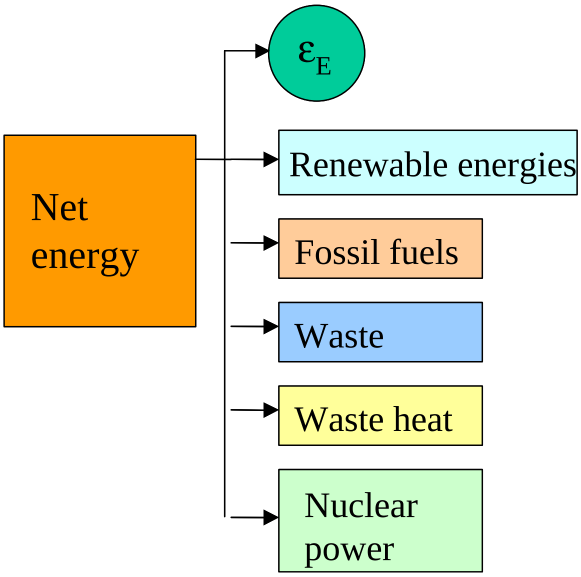

Figure 2.7 Division of net energy input into different categories of energy resources.

2.2.8 Low-priority factor

The Energy Eco-factor and the division into categories of energy sources may still not be enough in order to assess other aspects, than environmental impacts due to emissions of air, and the Energy Eco-factor has therefore an extension with a so-called low-priority factor.

The low-priority factor is meant to describe how important other aspects, than environmental impacts due to emissions of air, should be for making a difference in the assessment. These might be low-priorities due to political decisions or local energy situations. It is supposed to be used when choosing between two alternatives that have high difference in the Eco-factor score and the one with the highest score are using considerable more of the energy source category that is whished to be avoided. The low-priority factor is meant to facilitate the assessment and is not supposed to give a new score of the Eco-factor.

The low-priority factor implies that the source with low priority will receive a lower Eco-factor due to the size of the factor. It is not possible to increase the Energy Eco-factor by defining a low-priority factor, only to decrease the Eco-factor for the energy solution that is using the energy source category that is less preferred. Equation 2 will thereby be extended to:

$$I = \frac{\sum_{i}^{n}(k_i \cdot p_c \cdot Q_i)}{A}$$ **Equation 4**

where:

p = low-priority factor due to local situations or political decisions
c = category due to natural resources division (renewable energies, fossil fuels, waste, waste heat or nuclear power)

Example of use of low-priority factor

Consider two cases with two alternative energy solutions. Both cases are using European average electricity with 34 % nuclear power. Case 1 is using combustion of oil for heating and Case 2 is using combustion of natural gas. The difference between the two alternative are that alternative 1 is using more total energy but on the other hand is using less electricity (see Table 2.11).

Table 2.11 Electricity and heating input for the two considered cases.

Case no	Alternative energy solution	Total energy input kWh/(m², year)	EU average Electricity kWh/(m², year)	Heating kWh/(m², year)	Heating energy source	Energy Eco-factor[1]
1	1	160	120	40	Oil	47
	2	150	90	60	Oil	52
2	1	160	120	40	Natural gas	63
	2	150	90	60	Natural gas	64

[1] The Energy Eco-factor is calculated according to the description in 2.2.5-2.2.6

If only environmental impact due to emissions to air is considered should alternative 2 be used in both cases, due to highest score of the Energy Eco-factor (Table 2.11) and the lowest total energy use. However, if also other aspects are considered for nuclear power these considerations must increase the impact from nuclear power with 47 times for Case 1 and 11 times for Case 2 in order to get equal impact (equal Energy Eco-factor) for the two alternatives (Table 2.12). Higher low-priority factors will make alternative 1 more advantageous than alternative 2.

The environmental impact factor, $k_{nuclear\ power}$, is increased from 2 to 22 mELU/kWh in Case 2 and to 95 mELU/kWh in Case 1. The environmental impact factor in Case 2 is thereby considerable lower than for electricity production of oil, coal or EU average as well as the heating energy source natural gas (Table 2.13). The low-priority factor indicates that alternative 1 is the most beneficial. For Case 1 the low-priority factor indicates that alternative 2 still is the most beneficial.

Table 2.12 Low-priority factor and Energy Eco-factor for the two considered cases.

Case no	**Alternative energy solution**	**Use of nuclear power electricity** kWh/(m^2, year)	**Low-priority factor** $p_{nuclear\ power}$	**Low-priority Energy Eco-factor**
1	1	14	47	37
	2	20	47	37
2	1	14	11	61
	2	20	11	61

Table 2.13 Environmental impact factors for different energy sources

Energy source	**Environmental impact factor**[1] k_i mELU/kWh
Nuclear power	2.0
Heat by combustion of natural gas	27.4
Heat by combustion of oil	43.6
EU average electricity	34.2
Electricity by combustion of oil	65.4
Electricity by combustion of coal	79.3
Nuclear power with $p_{nuclear\ power} = 11$	22
Nuclear power with $p_{nuclear\ power} = 47$	95

[1] The environmental impact factors are calculated according to the description in Chapter 2.2.5

2.3 Indoor Climate

The Indoor Climate indicators used in IDEEB Eco-factor method are:

- IAQ: Percentage dissatisfied, PD
- Thermal comfort:
  - Overall thermal comfort: PPD (Predicted Percentage Dissatisfied)
  - Local thermal comfort:
    - Draught rating (DR)
    - Air temperature gradient, Percentage dissatisfied (PD)
    - Radiant temperature asymmetry, Percentage dissatisfied (PD)
    - Warm or cold floor, Percentage dissatisfied (PD)

For the indoor climate part, a similar approach as for the Energy Eco-factor is used, 100% equals "minimum possible dissatisfied", which are found in ISO 7730 (1991). 50% score equals a "normal" percentage of dissatisfied, which is represented by the "B" or medium level of expectation from CR 1752 (1998), see Tables 2.14 and 2.16.

2.3.1 Atmospheric comfort, IAQ

With atmospheric comfort we will understand the sensory perception of the air. For design purposes, and thus for classification, the quality of the air can be described with two different - optional -indicators.

- The "smell" of the air, with body odour from a person being the reference standard, but also building materials, ventilation ducts, etc. can be assessed in this way by trained sensory panels, see Figure 2.8. A problem is that it is difficult to assess these quantities in the design phase.
- Concentration of CO_2 in the air. This is a good indicator of human presence, since the human metabolism is closely linked to its CO_2 production. It is also much easier to measure than sensory perception, and thus to use as input for control systems. However, if substantial pollutants (apart from people) are involved, this indicator will not be adequate.

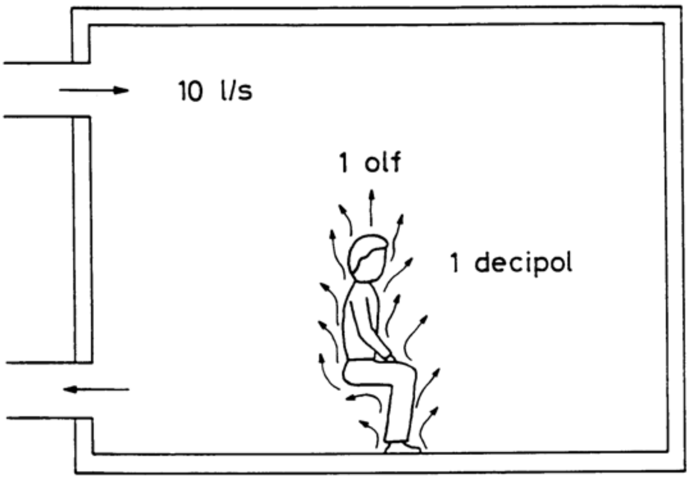

Figure 2.8 Sensory perception – the "smell" of 1 person (source strength, measured in olf), diluted by 10 l/s fresh air, defines the decipol unit (dp). (Fanger, 1988.)

IAQ comfort equation:

$$q_{v,o} \cdot (c_i - c_o) = 10 \cdot G \cdot \frac{1}{\varepsilon_v}$$

Equation 5

where:

q_{vo} = Air flow rate [l/s]
c_i = Perceived air quality [dp]
c_o = Perceived air quality of outside air [dp]
G = Sensory pollution load [olf]
ε_v = Ventilation effectiveness [-]

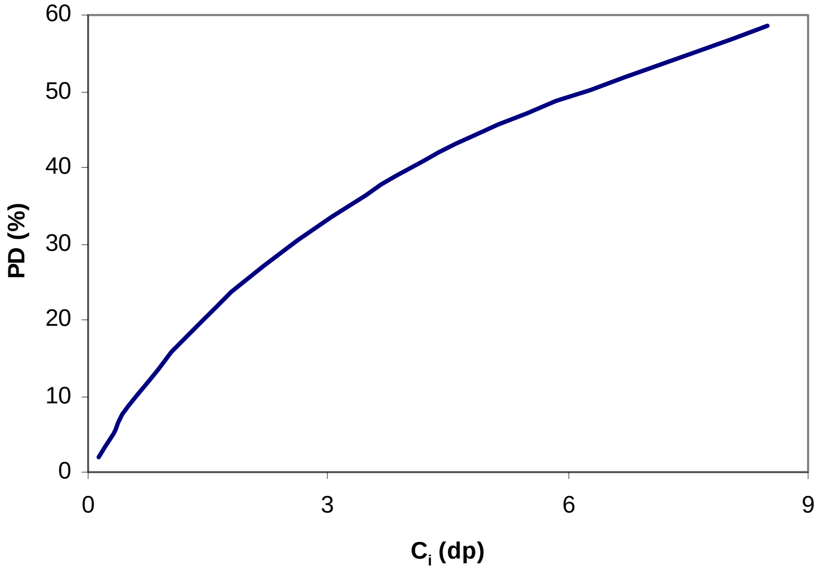

Figure 2.9 Percentage dissatisfied (PD) as function of perceived air quality in decipol (dp). (CR 1752, 1998.)

The percentage dissatisfied can be determined by using the perceived air quality, calculated with Equation 5, in Table 2.9. Another way of determines the percentage dissatisfied with IAQ is to use calculated or measured CO_2 concentration in Equation 6 or Figure 2.10.

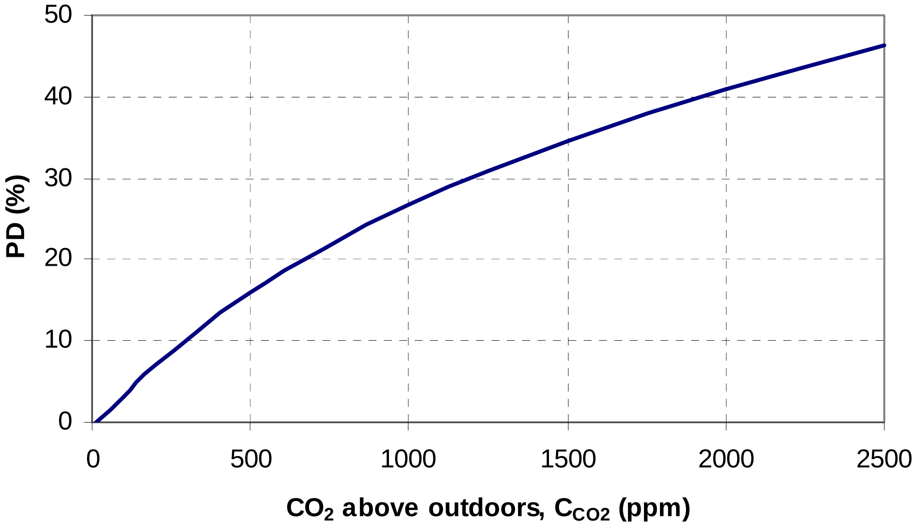

Figure 2.10 Percentage dissatisfied (PD) as function of CO_2 concentration (indicator of perceived air quality). (CR 1752, 1998.)

$$PD = 395 \cdot \exp(-15.15 \cdot C_{CO_2}{}^{-0.25}) \quad \textbf{Equation 6}$$

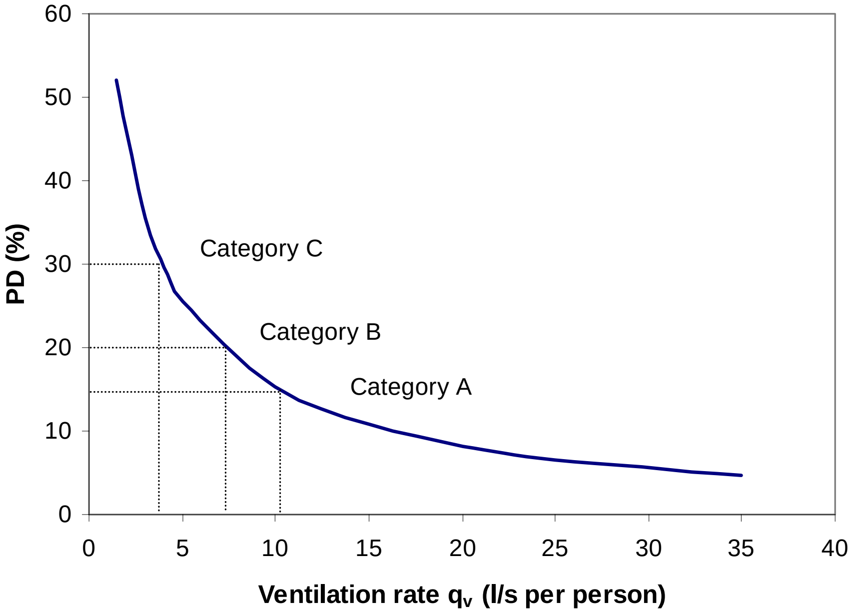

Figure 2.11 Percentage Dissatisfied (PD) as a function of ventilation rate, according to the IAQ-comfort equation (Equation 5). Categories A, B, C express different expectation levels as described in Table 2.14. (CR 1752, 1998.)

Table 2.14 CR 1752 (1998) also defines three categories of IAQ. The required ventilation rate is heavily dependent on the amount of environmental tobacco smoke in the room. Category B is used as “average” benchmark in the score function below.

Category	**Required ventilation rate** l/s × occupant			
	No smoking	**20% smokers**	**40% smokers** [c)]	**100% smokers** [c)]
A	10	20	30	30
B	7	14	21	21
C	4	8	12	12

Notes
- a) This table applies if it is assumed that the occupants are the only source of pollution
- b) This table applies to a non-smoking environment and for different levels of tobacco smoking.
- c) For 40-100% smokers, the requred ventilation is equal to the value for 40% smokers, since smokers are more tolerant towards tobacco smoke than non-smokers.

The airflow rate for category B in Table 2.14 will be transformed to percentage dissatisfied in Figure 2.11 and thereafter be used as the "average" benchmark in the score function below (Figure 2.12).

Alternatively, the percentage dissatisfied (PD) indicator can be determine by measuring or calculating the CO_2-concentration and transform it with the help of Figure 2.10.

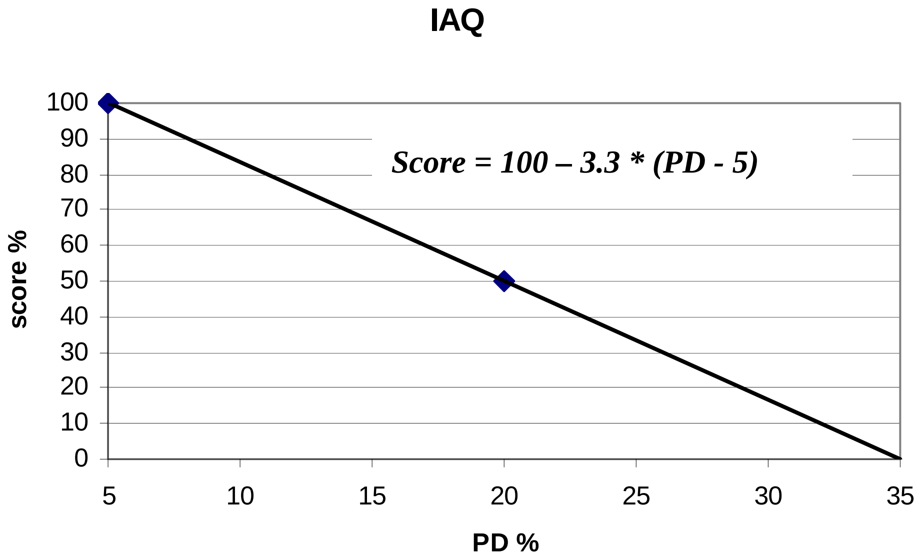

Figure 2.12 Score function for IAQ with indicator PD (Percentage Dissatisfied). The upper benchmark is chosen as 5% PD, since it is practically impossible to achieve better results, as Figures 2.9 – 2.11 indicate.

2.3.2 Thermal comfort

The ambition when designing buildings for thermal comfort is thermal neutrality, that as few occupants as possible feel any form of thermal stress. As suggested by ISO 7730 (1998), we divide thermal stress in two main subcategories: overall thermal balance, and local discomfort.

Overall thermal state

The overall perception of thermal comfort is described by the PMV-index (Predicted Mean Vote). The PMV equation for thermal comfort is a steady-state model. It is an empirical equation for predicting the average vote of a large number of people on a 7 point scale (-3 to +3) of thermal comfort. The equation uses the steady state heat balance of the human body and develops a link between the thermal comfort vote and the degree of stress or load on the body (e.g sweating, vaso-constriction, vaso-dilation) caused by any deviation from perfect balance. The greater the load, the more the comfort vote will deviate from zero.

The partial derivative of the load function is estimated by exposing enough people to enough different conditions to fit a curve. PMV is arguably the most widely used thermal comfort index today. The ISO 7730 (1991), "Moderate Thermal Environments - Determination of the

PMV and PPD Indices and Specification of the Conditions for Thermal Comfort," uses limits on PMV as an explicit definition of the comfort zone.

The PMV equation only applies to humans exposed for a long period to constant conditions at a constant metabolic rate (Met). Conservation of energy leads to the following heat balance equation:

$$H - E_d - E_{sw} - E_{re} - L = R + C$$ **Equation 7**

where:

H = internal heat production,
E_d = heat loss due to water vapor diffusion through the skin,
E_{sw} = heat loss due to sweating,
E_{re} = latent heat loss due to respiration,
L = dry respiration heat loss,
R = heat loss by radiation from the surface of a clothed body,
C = heat loss by convection from the surface of a clothed body,

The equation is expanded by substituting each component with a function derivable from basic physics. All of the functions have measurable values with the exception of clothing surface temperature and the convective heat transfer coefficient, which are functions of each other. To solve the equation, an initial value of clothing temperature is estimated, the convective heat transfer coefficient is then computed, and a new clothing temperature calculated. This is continued by iteration until both are known to a satisfactory degree. If the body is assumed not to be in thermal balance, the heat equation can be re-written as:

$$L = H - E_d - E_{sw} - E_{re} - R - C$$ **Equation 8**

where:

L is the thermal load on the body.

Define thermal strain or sensation, Y, as some unknown function of L and metabolic rate. Holding all variables constant except air temperature and metabolic rate, use mean votes from climate chamber experiments to write Y as function of air temperature for several activity levels. Then substituting L for air temperature, determined from the heat balance equation above (Equation 8), evaluate the partial derivative of Y with respect to L at Y=0 and plot the points versus metabolic rate. An exponential curve is fit to the points and integrated with respect to L. L is simply renamed "PMV" and we have (in simplified form):

$$PMV = \exp(Met) * Y$$ **Equation 9**

PMV is "scaled" to predict thermal sensation votes on a seven-point scale (see Table 2.15) by virtue of the fact that for each physical condition, Y is the mean vote of all subjects exposed to that condition.

Table 2.15 The PMV-index used to describe a person's overall perception of thermal comfort (ISO 7730, 1991).

PMV- index (thermal sensation votes)	
+3	hot
+2	warm
+1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold

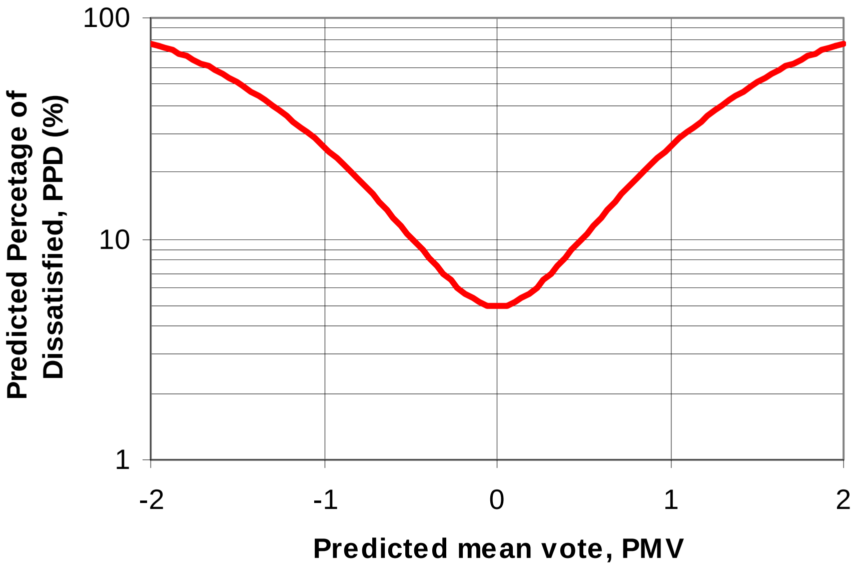

Figure 2.13 The PPD-index (Predicted Percentage Dissatisfied) is a function of PMV, for a large number of persons placed in the same environment (ISO 7730, 1991).

Category B, in Table 2.16, is used as "average" benchmarks in the following score functions for overall thermal state, and the four local discomfort categories.

Table 2.16 CR 1752 (1998) defines three categories of thermal environment. Category B will be used as "average" benchmarks in the following score functions.

	Thermal state of the body as whole		Local discomfort			
Category	Predicted percentage of dissatisfied PPD %	Predicted mean vote PMV %	Percentage dissatisfied due to draught DR %	Percentage dissatisfied due to air temperature difference PD %	Percentage dissatisfied due to warm or cool floor PD %	Percentage dissatisfied due to radiant asymmetry PD %
A	<6	0.2<PMV<+0.2	<15	<3	<10	<5
B	<10	0.5<PMV<+0.5	<20	<5	<10	<5
C	<15	0.7<PMV<+0.7	<25	<10	<15	<10

As upper benchmark of 5% dissatisfied is used in recognition of the difficulties involved in exceeding this mark, see Figure 2.13. As with the energy indicator, it could be theoretically possible to score more than 100%, but only by adopting very unusual and expensive methods. In the case of indoor comfort, this would require that every occupant in the building are fully in individual control of his/her microenvironment. This situation falls outside the definitions of ISO 7730 (1991).

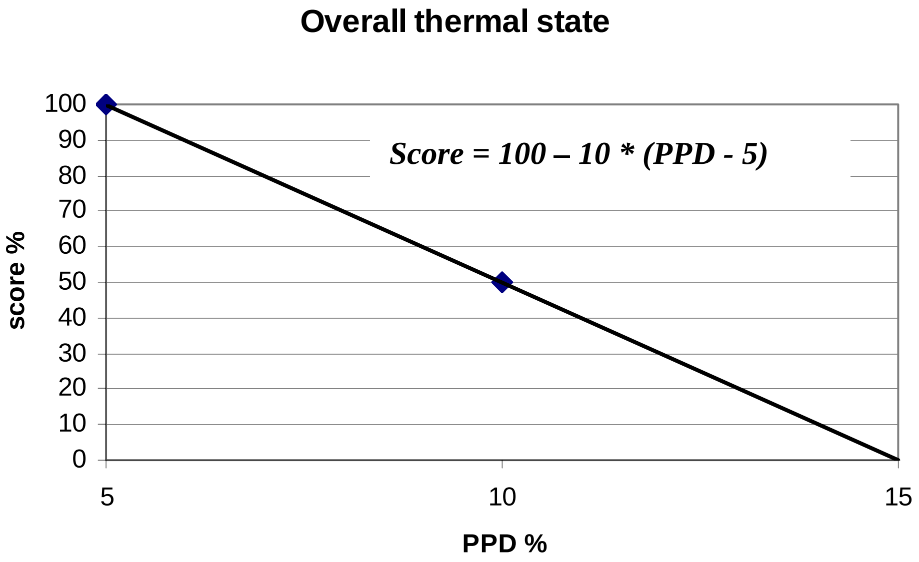

Figure 2.14 Score function for overall thermal state of the whole body with indicator PPD.

Local discomfort

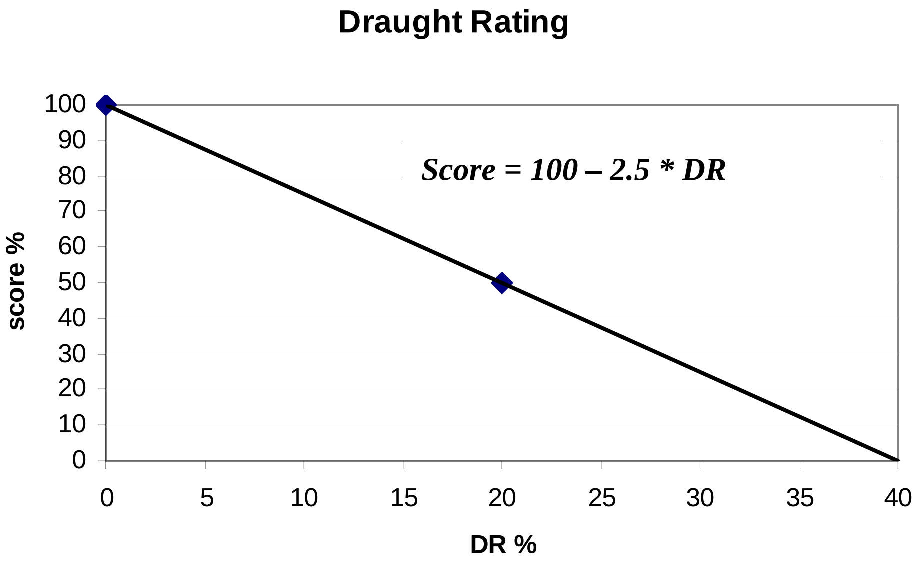

Figure 2.15 Score function for local thermal discomfort due to draught with indicator DR (Draught Rating).

$$DR = (34 - t_a) \cdot (\overline{v_a} - 0{,}05)^{0{,}62} \cdot (0{,}37 \cdot \overline{v_a} \cdot Tu + 3{,}14)$$

Equation 10

where

t_a : ambient air temperature
v_a : mean air velocity
Tu : turbulence intensity

The draught rating indicator can be determine by measuring or calculating, t_a, v_a and T_u and calculate DR with Equation 10.

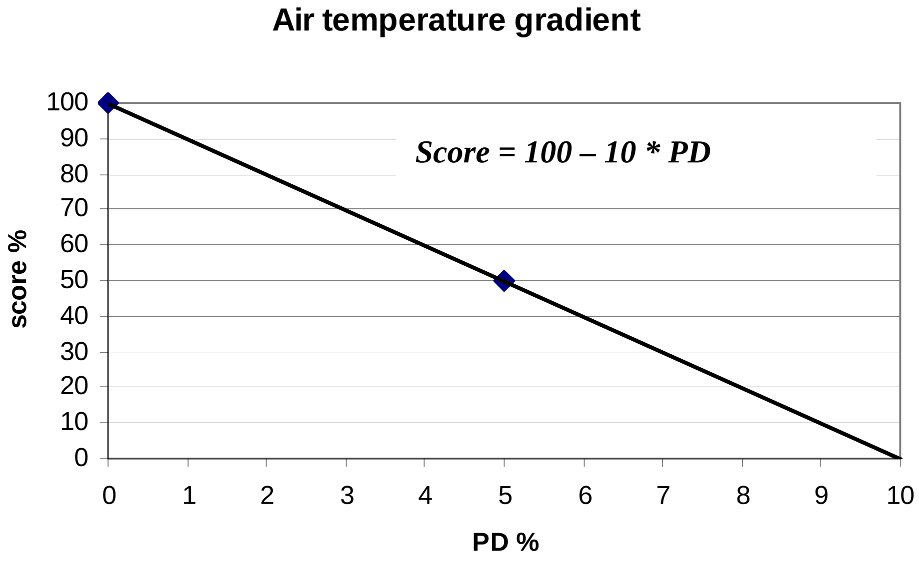

Figure 2.16 Score function for local thermal discomfort due to vertical air temperature gradient.

The percentage dissatisfied (PD) indicator can be determine by measuring or calculating the vertical temperature and transform it with the help of Figure 2.17.

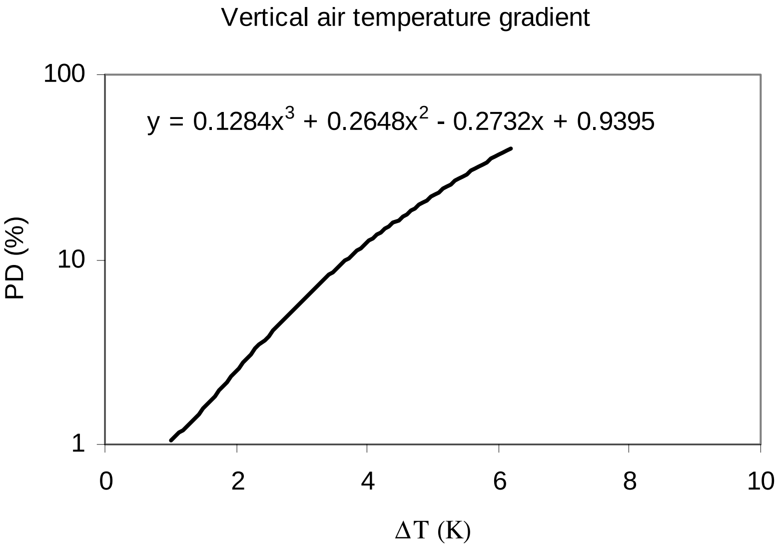

Figure 2.17 Percentage dissatisfied (PD) as function of a vertical air temperature gradient, expressed as a temperature difference between head and feet (defined by curve fit to figures derived from ISO 7730 (1991), which is an approximation).

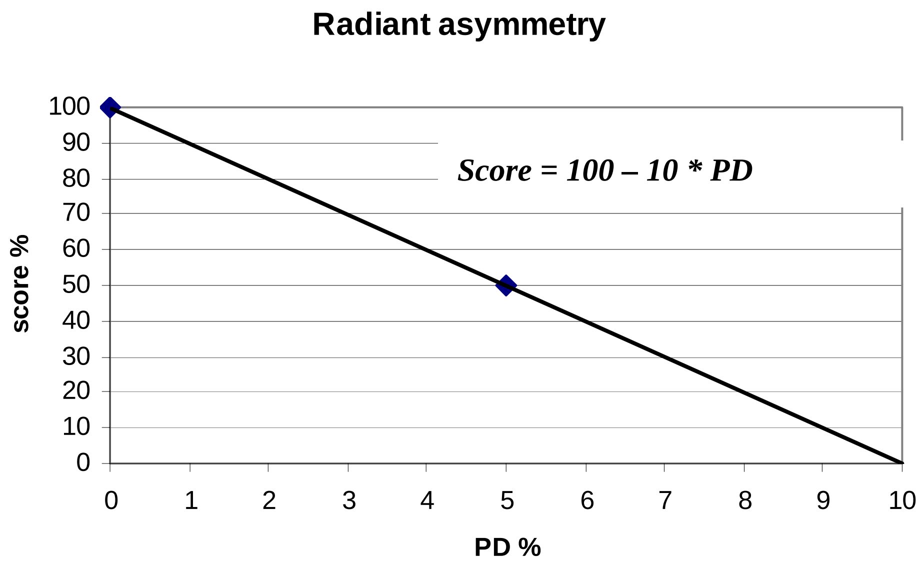

Figure 2.18 Score function for local thermal discomfort due to radiant temperature asymmetry.

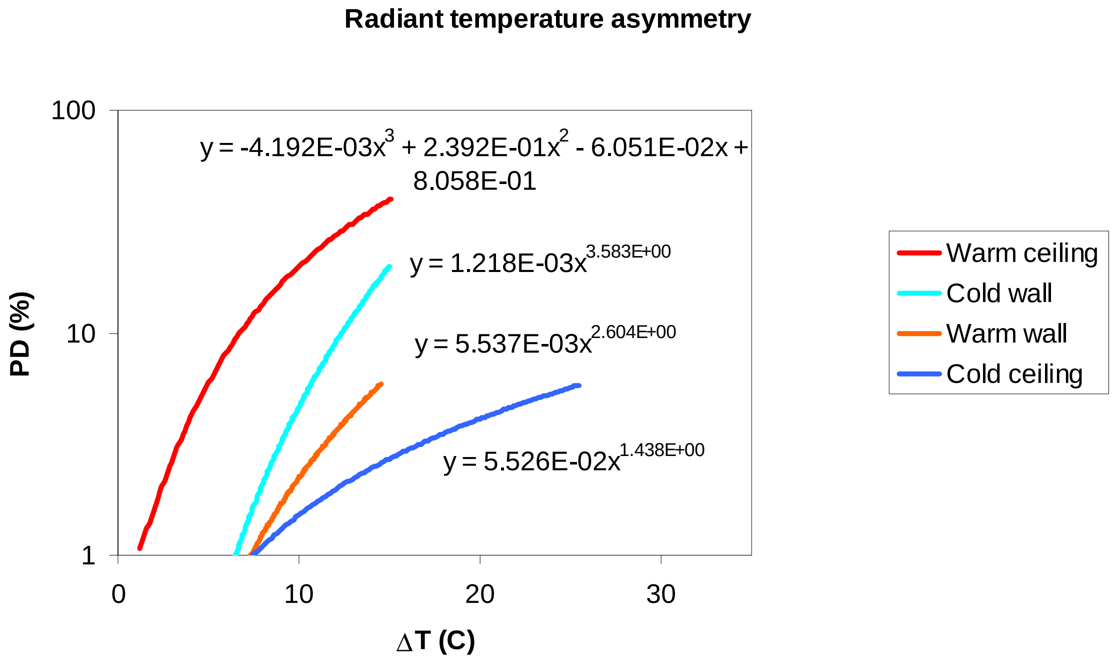

Figure 2.19 A difference in radiant temperature from two surfaces on opposite sides of the body will cause thermal stress. The degree of stress depends on the orientation of the surfaces. (CR 1752, 1998.)

By measuring or calculating surface temperatures for the internal surfaces in a room the percentage dissatisfied (PD) indicator can be determined.

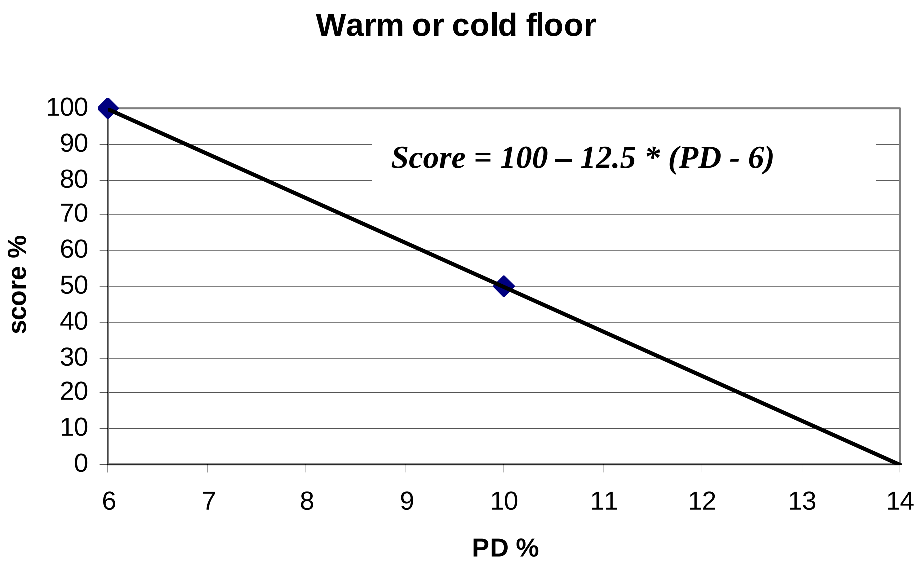

Figure 2.20 Score function for local thermal discomfort due to warm or cold floor

The percentage dissatisfied (PD) indicator can be determine by measuring or calculating the floor temperature and transform it with the help of Figure 2.21.

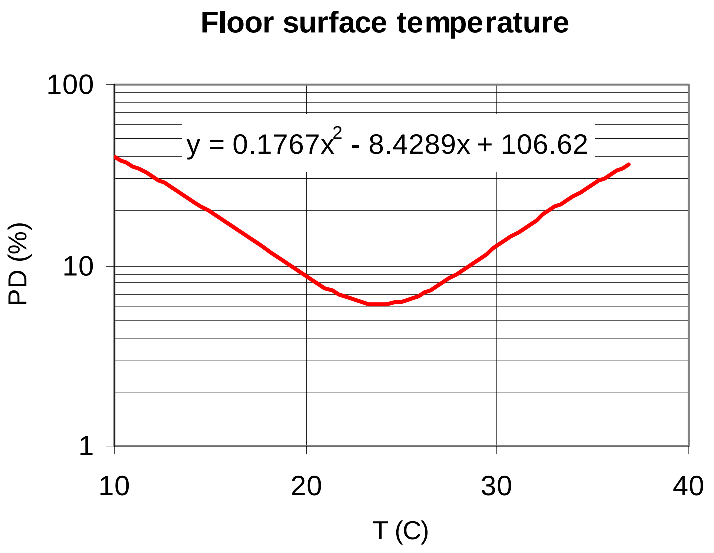

Figure 2.21 Floor temperature as function of percentage dissatisfied (PD) (ISO 7730, 1991). Individual differences in perception is the reason it is not possible to reach below 6% PD. This is why 6% is chosen as 100% benchmark in Figure 2.20.

3. Weighting

All of the studied tools adopt some kind of weighting of the raw output data, in order to add effects from different subcategories and thereby present them in a more understandable form. The reason is that a large number of quantitative indicators tend to be confusing and usually not very helpful to the design process.

3.1 Types of weighting

The method practically universally adopted is using two types of weighting:

- Explicit: For addition of main categories, which tend to be very diverse in nature, and therefore difficult to link to physical indicators. A typical way to find weighting factors is to ask "Authoritative Panels", which can be divided into:
    - Expert panels (example GBTool)
    - Societal group consensus (example BREEAM)
    - User defined, e.g. by organisation priority (example MCDM-23).

- Implicit: Contained in goals, standards or in benchmarks, having effect on subcategory scores.
    - Authorised goals or standards
        - Political targets
            - National
            - International (e.g. U.N. agreements)
        - Scientifically based targets

An implicit example of weighting from the Dutch Government Building Agency's assessment tool: Year 1990 is used as a reference year and the reduction goal – based on scientific considerations about sustainable development - is to reach a twentieth of 1990's level in 2030. These are the benchmarks used to define a score function.

3.2 Weighting of impact categories

The proposed Eco-factor method has adopted the following strategy regarding weighting factors. The two main environmental impact categories will be calculated in three (optional) ways:

1. Equal weight. Categories on the same "level" of importance are given equal weight.

2. Weighting factors from other, common tools. Showing weighting factors derived in different ways and by different people can illustrate for the user the uncertainty involved in this step.

3. User-defined weighting factors, e.g. by company policy.

3.2.1 Weighting of main impact categories

The proposed Eco-factor method has two main impact categories; energy related environmental impacts and indoor environment. The weighting of these categories in other related assessment tools is presented in Table 3.1. Since those methods have several impact categories the weighting factors are calculated as percentage of the total weighting of energy and indoor climate, and are presented both with daylighting included and excluded.

Table 3.1 Default weighting factors from related assessment tools.
(Calculated as percentage of total IDEEB relevant categories.)

Daylighting		*GBTool*	*LEED*	*BREEAM*
Included	Energy	50	53	65
	Indoor Climate	50	47	35
Excluded.	Energy	60	57	68
	Indoor Climate	40	43	32

As shown in Table 3.1 energy is considered just somewhat more important than indoor climate. The focus and aim with the IDEEB project is that good indoor climate should not be deteriorated by too ambitious energy optimisations. Therefore, in the Eco-factor method, the default values for weighting of energy and indoor climate are set equal to 50%.

3.2.1 Weighting of indoor climate categories

Table 3.2 shows relative weighting factors for different indoor climate categories for two related assessment tools. The two methods’ authoritative panels have differing views of the weight factors, and even of how to define performance, at this level of detail.

Table 3.2 Relative weighting factors for indoor climate categories in % of total indoor climate score.

Indoor climate category	*GBTool*	*LEED*
Ventilation	16.9	13.3
Source control	20.6	33.3
Thermal comfort	31.2	13.3
Daylighting	31.2	13.3
Other (systems, procedures)		26.6

In the Eco-factor method instead a different approach is proposed for weighting subcategories below the level of the Indoor Climate Eco-factor. Thermal comfort and indoor air quality are weighted equal while the worst performing subcategory of local and overall thermal comfort are defining the level for thermal comfort. Four levels of detail are defined for calculating the Indoor climate part of the Eco-factor, as illustrated in Figure 3.1.

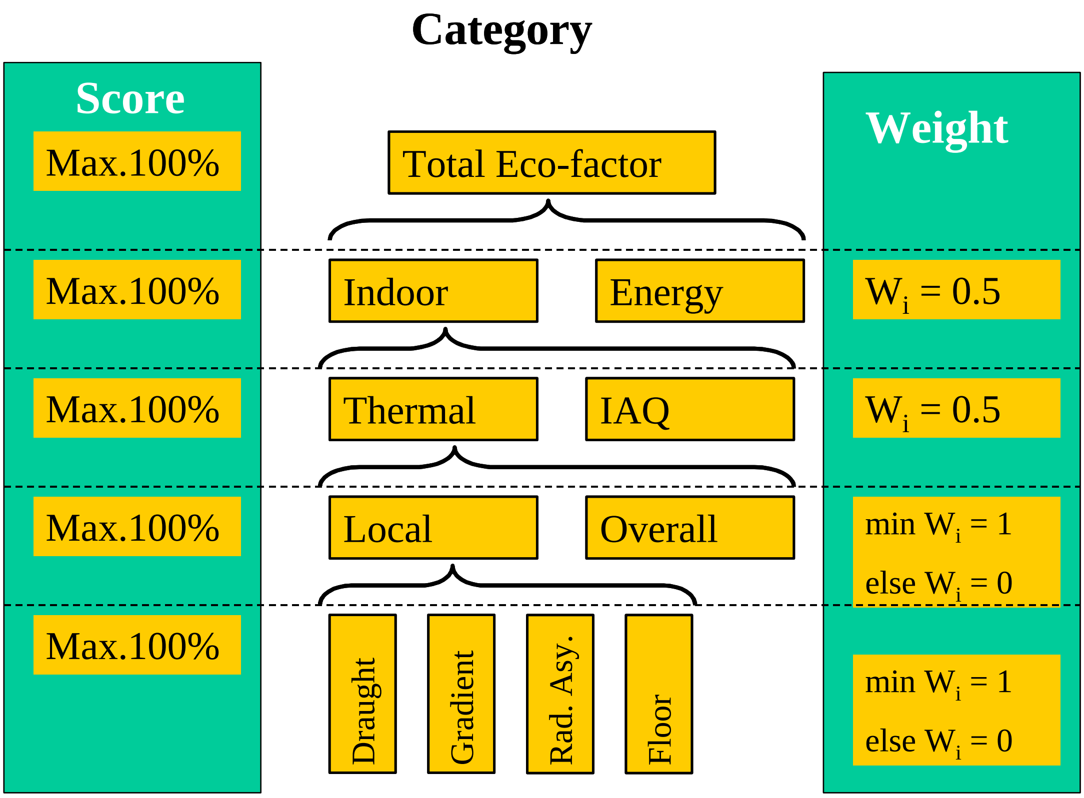

Figure 3.1 Weight factors used to add subcategories. $W_i = 0.5$ means that each category is weighted by 50%. “min $W_i = 1$, else $W_i = 0$” means that the subcategory with minimum score is weighted with 100%, all other categories are weighted with 0%, so that the worst performing subcategory defines the level.

Indoor climate main categories

The overall “score” for indoor climate is composed by weighted addition of the score for the subcategories “Thermal comfort” and “Indoor Air Quality”. Here, we suggest using as IDEEB default an “equal weighting” approach, meaning 50/50. The reason for this is that the categories are very different in their physical nature and therefore difficult to weight. We have not found any scientific reason for giving different weight factors. As an option, we will supply possibility for viewing the result of employing weight factors of the “authoritative panel” method, taken from other assessment tools, and for defining one’s own weight factors.

Thermal comfort subcategories

We have not found weight factors in the literature for the lowest two levels in the hierarchy. Indeed, this would appear to run against the general idea of the ISO 7730 (1991) standard, which demands that all issues are addressed, satisfactory.

This is quite logical as indicated in following example: Despite the fact that a person is in “overall” thermal balance, feels no discomfort due to radiant temperature asymmetry, floor temperature, or air temperature gradient, it is still perfectly possible to feel highly uncomfortable due to draught. So, it would not be reasonable to have a high “score” if only 4 out of 5 objectives are fulfilled. If you fail on one of the objectives, the whole solution has failed.

Since individual scores cannot be added, we have decided to adopt a different approach: the sub-indicator, which achieves the lowest score, defines the final score on each level. This will assist to quickly identify problems, instead of obscuring problems by adding several subcategories to an overall score.

It is possible with this approach to exclude the lowest subcategory in the early design phase, since sufficient data may not be present. The result will still be useful from a design perspective, since the overall thermal balance will usually need to be settled first, before considering details. The Indoor Climate Eco-factor can be defined by the overall thermal state alone, and local conditions assessed by rules of thumb or qualitative guidelines. In later design phases, computer simulations should give sufficient detail about mainly temperature, concentration, and air velocity fields to make optimized solutions for local conditions.

3.2.2 Weighting of energy related impacts

The Energy Eco-factor has one main category as seen in Figure 3.2. The weighting for this energy category is based on total emissions for the life cycle of all energy sources and is not done by different subcategories directly. Different emission substances are weighted by use of recognized environmental assessment methods that have defined indexes for the different substances. The indexes describe the substance contribution to environmental impact effects as e.g. global warming or acidification, and their related impact on human health and the quality of the ecosystem. The weighting of emission substances can also be done with indexes for impacts on different environmental effects.

The advantage with weighting by indexes for impacts on different environmental effects is that the weighting will be more or less objective while the disadvantage is that each environmental impact is considered separately. To get a total picture of all impacts on environmental effects the user must do an own valuation between the effects.

The advantages with using recognized environmental assessment methods for the weighting is that the result will consist of one figure. But on the other hand, this weighting is subjective and it might not be in line with the users considerations. It is therefore recommended to do the assessment for several different recognized environmental assessment methods. If all are showing nearly the same result it will strengthen the final assessment.

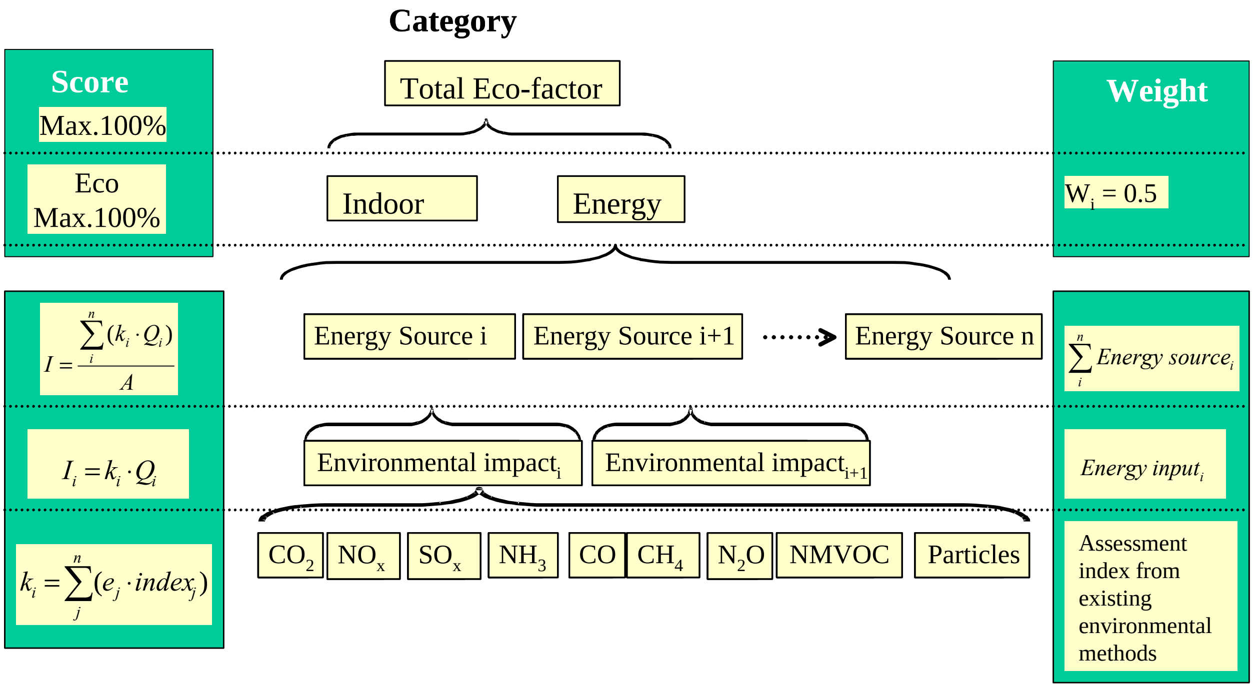

Figure 3.2 Weight factors used to add subcategories. $W_i = 0.5$ means that each category is weighted by 50% etc. The Energy category is calculated by total emissions and weighting of the emitted substances impact on the environment due to an environmental assessment method.

4. Resulting Eco-factor

The method for the Eco-factor has two core Environmental Impact Categories:

- Environmental impacts due to energy use
- Indoor Environment

In Chapter 3 it was showed how both impact categories can be presented by single Eco-factors that below will be put into one single figure (Eco-factor).

4.1 Calculation of Eco-factor

First the Eco-factors for the two core Environmental Impact Categories are calculated individually.

Input data needed for Eco-factor calculation

Input data from energy simulations etc:
- Energy sources
- Energy use for each energy source (kWh/(year, m^2))
  - Energy input for heating and cooling

Input data from indoor climate calculations:
- Thermal comfort
- IAQ

Input from user:
- Priority-factors
- Choice of environmental assessment methods

The two Environmental Impact Categories have separate environmental assessments. These will be performed by making an inventory of indicators and thereafter a classification, a characterization and a weighting of the indicators that finally will be normalized to a 0-100 % Eco-factor. The Energy Eco-factor and the Indoor Climate Eco-factor will thereafter be weighted together into one final figure (see Figure 4.1).

Weighting of total Eco-factor

The Eco-factor (ε) should preferably be an easily understandable scale from 0-100%, thus, on each level in the hierarchy:

$$\varepsilon = \frac{\sum \varepsilon_i \cdot W_i}{\sum W}$$

Equation 11

where:

W = weighting factor.

This is similar as in MDCDM-23 (Balcomb et al., 2001). The weighting is very simple to perform as it is now, but this way of describing the weighting opens up for adding more impact categories to the Eco-factor, while keeping the same fixed reference frame.

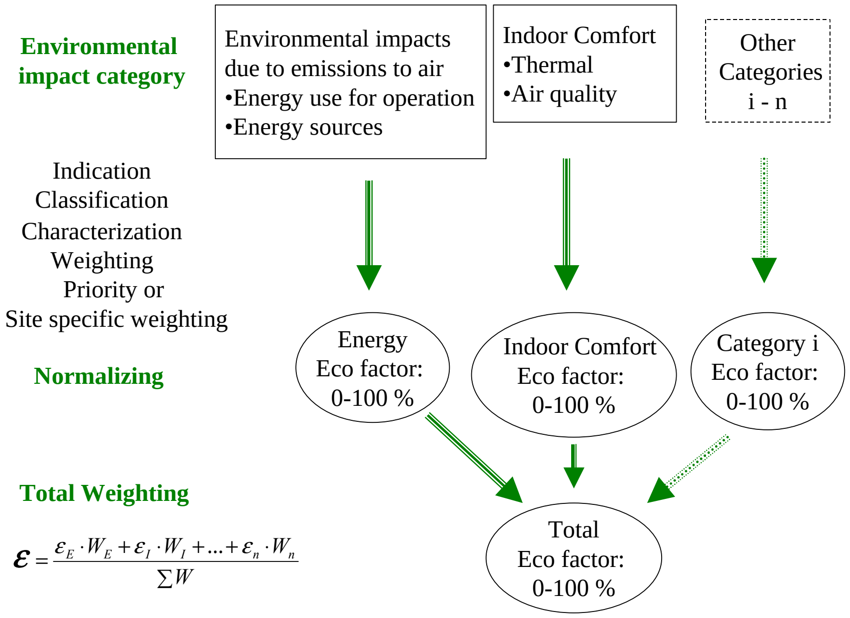

Figure 4.1 Illustration of weighting of the total Eco-factor in the IDEEB concept

The total procedure of calculating the Eco-factor is illustrated in Figure 4.1. This way of arranging things things is similar to BREEAM (Yates et al., 1998) as shown in Figure 4.2. It is also similar to ESCALE (Gérard et al., 2000)), except for the numeric scale chosen in that tool.

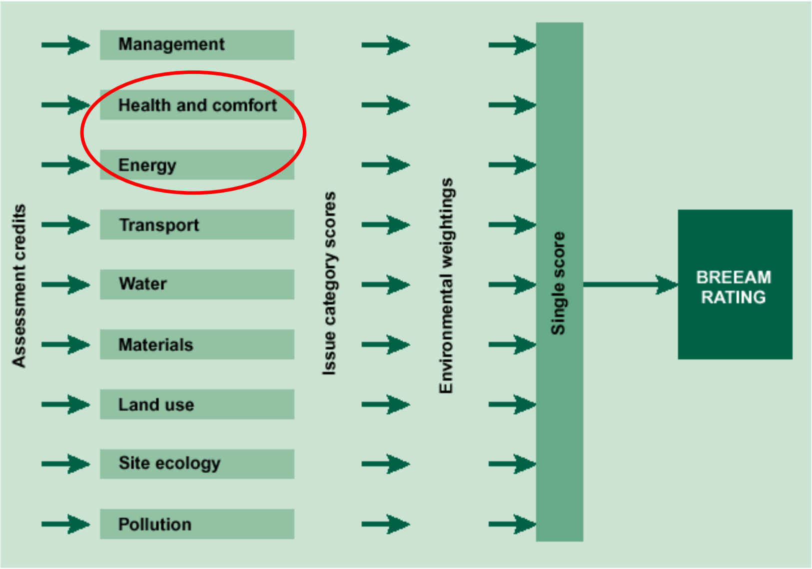

Figure 4.2 Illustration of rating in the BREEAM method (Yates et al., 1998).

Example

The following example is based on data from a case study of B&O Headquarter building in Denmark (Bjørn and Brohus, 2003). Table 4.1 shows the energy use for the B&O case study.

Table 4.1 Energy use for B&O case study.

	Heating	**Electricity**		
		HVAC	Lighting	**Total building operation**
Energy use (kWh/m^2)	**98**	1.7	64	**66**

Since no information is available about the electricity use for appliances, we must calculate the Energy Eco-factor using benchmark data including electricity use for building operation only. The indicator for emission impact ($I_{25\%}$) for total building operation of an average European office is calculated according to Table 4.2 by data available from Tables 2.2 and 2.7. We assume that the building uses the same mix of energy sources as the “average” EU office (see Table 2.4).

Table 4.2 Emission impact indicator ($I_{25\%}$) for an average European office.

Impact indicator unit	**Heating**	**Electricity**					**Heating and Electricity**	
		HVAC	Lighting	Appliances	Total	Total building operation	Total energy use	Total building operation
mELU/(m^2, year)	4975	1201	1394	1797	4392	2596	9368	**7571**
mPt/(m^2, year)	393	144	167	215	526	311	918	**703**
kg CO_2-eqvivalents / (m^2, year)	42.7	9.5	11.0	14.2	34.6	20.5	77.3	**63.1**
mole H+/(m^2, year)	0.94	1.0	1.2	1.5	3.7	2.2	4.6	**3.1**

Tables 4.1 and 2.2 give the emission impact indicator (I) for the B&O case study while Equation 1 and Tables 4.2 and 4.3 give the Energy Eco-factor, see Table 4.3.

Table 4.3 Emission impact indicator (I) and Energy Eco-factor (ε_E) for the B&O case study.

Environmental assessment method	Unit	I Heating	I Electricity	ε_E Energy Eco-factor (0-100%)
EPS	mELU/kWh	2255	3238	45.6
Eco-indicator 99	mPt/kWh	256	270	43.9
Greenhouse Effect	g CO_2-qvivalents/kWh	27.8	17.8	45.8
Acidification	mmole H+/kWh	0.61	1.9	39.8
Average				**44**

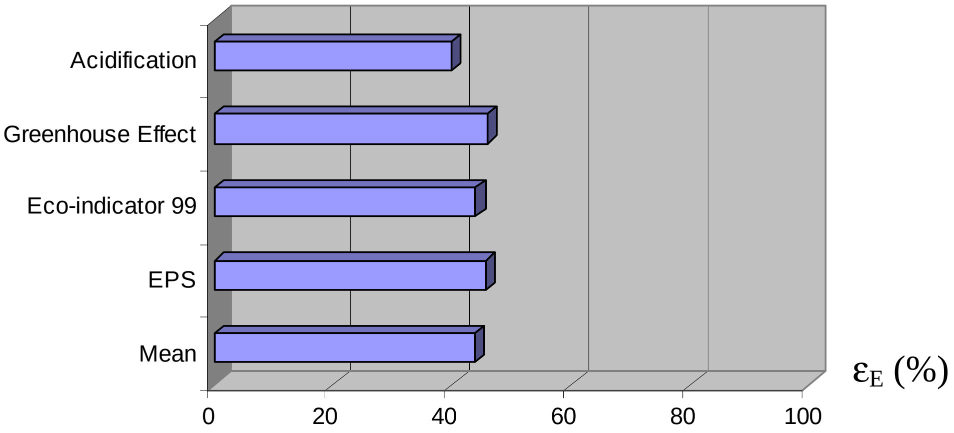

Figure 4.3 The Energy Eco-factor for the B&O case study for different environmental assessment methods. “Mean” is the mean value of the four different methods, and is used as input for the total Eco-factor.

For the local thermal comfort the temperature asymmetry in the B&O case study is small and insignificant and the vertical temperature gradient is less than 1°C/m (Bjørn and Brohus, 2003). This mean that discomfort due to draught will be the worst performing subcategory and draught rating will define the level for local thermal comfort according to Figure 3.1. Draught rating, DR, and overall thermal comfort in the form of PPD (predicted percentage of dissatisfied) are given for three typical climatic situations (Bjørn and Brohus, 2003). The values are given in Tables 4.4 and 4.5 together with corresponding scores according to Figures 2.5 and 2.14.

Table 4.4 Draught rating, DR, and corresponding scores for the B&O case study.

Climatic situation	DR (%)	Score (%)
Winter	3.9	90
Summer	7.1	82
Atumn	4.6	89

Table 4.5 Overall thermal comfort of the whole body with the indicator, PPD, and corresponding scores for the B&O case study.

Climatic situation	PPD (%)	Score (%)
Winter	6.3	87
Summer	5.7	93
Atumn	5.5	95

The worst situation defines the sub-scores (Table 4.6) for total thermal comfort according to Figure 3.1. For all climatic situations the minimum score is 82%, which defines the score for total thermal comfort.

Indoor air quality, IAQ, is assessed indirectly by means of the CO_2 concentration assuming low emission of volatile organic compounds from building materials. The maximum CO_2 level is close to 1000 ppm even though the BEMS is overruled due to rain or low external temperature and the supply openings are kept closed (Bjørn and Brohus, 2003). This means about 500 ppm above outdoors CO_2-concentrations, which correspond to 16% dissatisfied, PD, according to Figure 2.10. This corresponds to a IAQ score of 64%. The Indoor Climate Eco-factor can then be calculated with the 50% weighting according to Figure 3.1, which is shown in Equation 12.

$$\varepsilon_I = 0.5*82\% + 0.5*64\% = 73\% \qquad \textbf{Equation 12}$$

The total Eco-factor is also given by 50% weighting of energy and indoor climate according to Figure 3.1, which is shown in Equation 13.

$$\varepsilon = 0.5*44\% + 0.5*73\% = 59\% \qquad \textbf{Equation 13}$$

The total Eco-factor, ε, for the B&O case study is 59%.

4.2 Presentation of results

The presentation of the result for the total Eco-factor should allow an overview of the results from different design strategies. The presentation should include the scoring system, where it is possible to see scores on every “level” in the hierarchy, with clear indications of how the score was arrived at.

One way of presenting the total Eco-factor is to envisage “pie” charts as shown in Figure 4.4. Here the contributions from indoor climate and energy use respectively, are clearly shown. It is also visualized how far the two core Eco-factors are from maximum value. Another way of presenting the total Eco-factor is to use “bar” charts as shown in Figure 4.5. By “bar” charts it is clearly visualized how far the total Eco-factor is from its maximum value. Bar charts enable swift comparison of several cases.

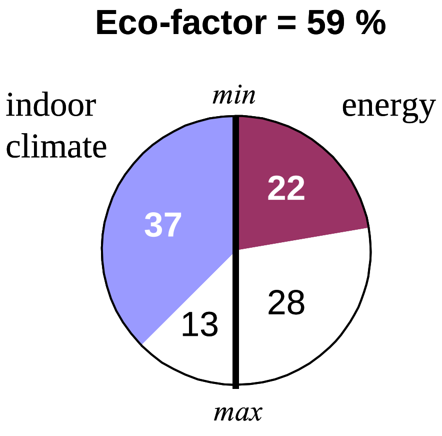

Figure 4.4 Presentation of the Eco-factor for B&O case study, based on the same energy sources as the “average” EU office.

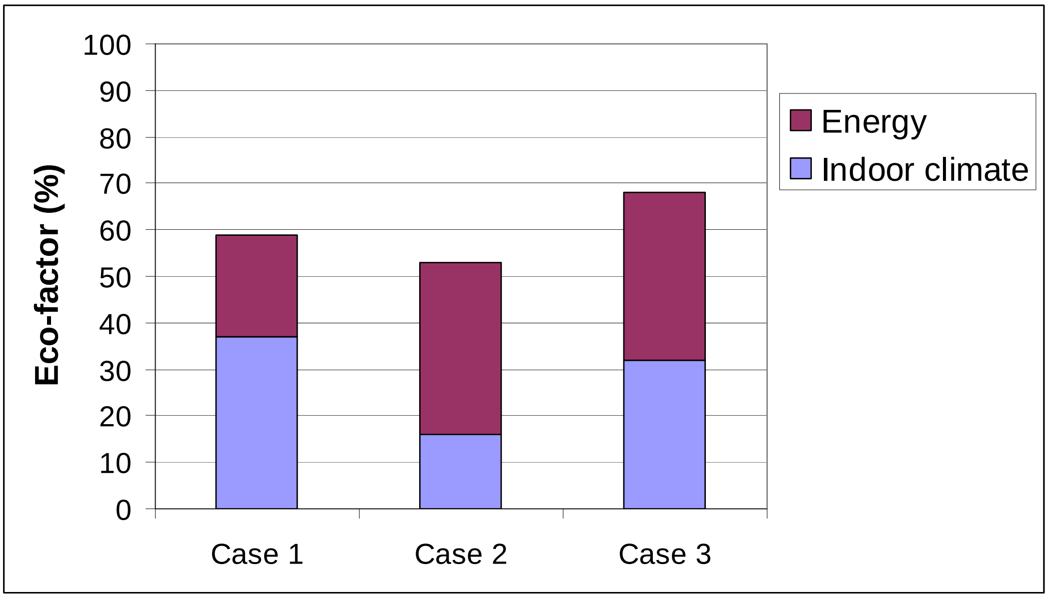

Figure 4.5 Example of ”bar” chart format. Bar charts enable swift comparison of several cases.

Ranking of results

In Chapter 1.3 it was mentioned that the assessment tools should be capable of quickly ranking results, so that trivial issues can be dismissed. Therefore the reverse quality of “performance” has been defined as “improvement potential”, *IP*, for subcategories below the Indoor Climate and Energy Eco-factor level. The improvement potential should assist in identifying the part of the design, which is causing the trouble.

Definition of Improvement potential (*IP*):

$$IP = W_i \cdot (100 - C_i) \qquad \textbf{Equation 14}$$

where:

C = classification score (0-100%)
i = indicator for subcategory i
W = weighting factor for transformation to total Eco-factor;
for indoor climate subcategories $W_i = 0.25$
for energy subcategories $W_i = 0.5$

This means that the improvement potential is proportional to the “environmental load” of each subcategory of energy use and indoor climate. The *IP* score tells us how many percent we can improve each subcategory. To have the *IP* expressed directly in the (total) Eco-factor scale, the term W_i includes weighting factors to transform the score from the relevant subcategory to the total Eco-factor level ($W_i = 0.5 \cdot 0.5 = 0.25$ for indoor climate, $W_i = 0.5$ for energy categories). Figure 4.6 shows the improvement potential for different subcategories in the B&O case study. Roughly speaking the “missing” points (to obtain an Eco-factor of 100%) are found in the improvement potential, *IP*.

For energy categories the classification score, according to Equation 1, can be calculated with:

$$C_i = \varepsilon_{E,i} = 100 - \frac{75 \cdot I_i}{I_{25\%}}$$ **Equation 15**

Equation 12 and 13 will give:

$$IP = W_i \cdot \left(\frac{75 \cdot I_i}{I_{25\%}} \right)$$ **Equation 16**

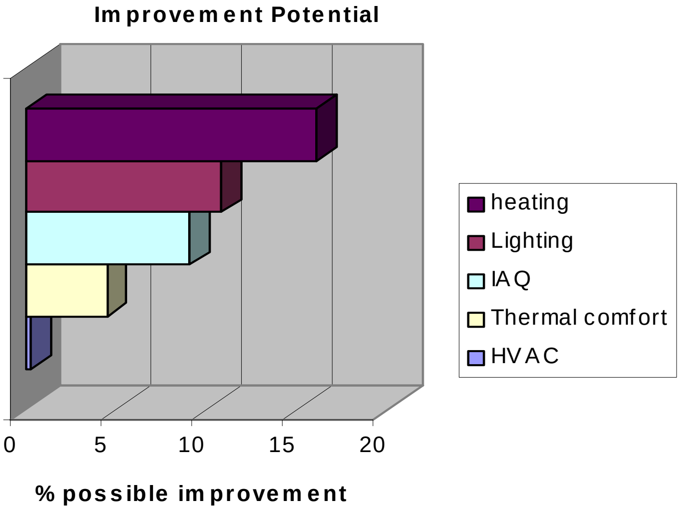

Figure 4.6 Presentation of improvement potential for different subcategories in the B&O case study.

It is important that the input to the Eco-factor is not “hidden”. It should also be possible to compare individual components directly, without the score functions, weighting, ranking etc. This would be useful especially in later design phases, where details about the technical systems are considered. An output for instance in kWh/m^2 per year, as in the example in Figure 4.7, facilitates economical calculations, which must be carried out in parallel with the environmental assessment.

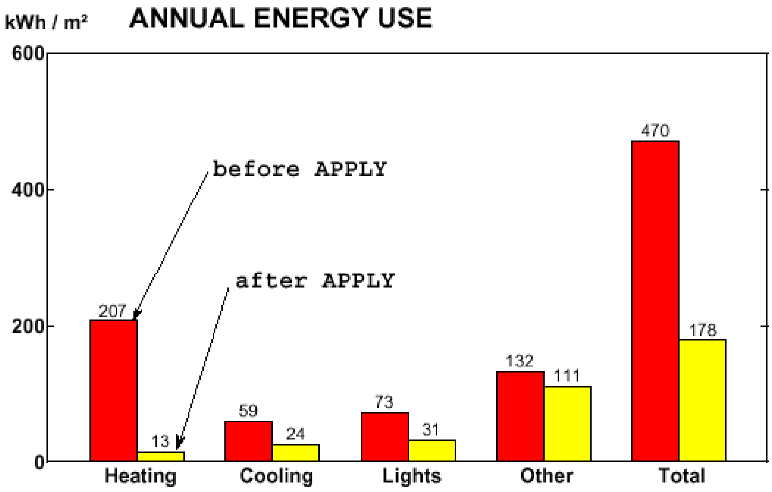

Figure 4.7: Example of an extensive indicator (specific energy use) broken down in a sub-profile showing individual components (ENERGY-10).

4.3 Use of Eco-factor assessment in integrated design processes

The Eco-factor method is supposed to be used for assessment of energy related environmental impact and indoor climate of alternative choices of technical energy-solutions, which are developed for a specific building in an integrated design process. Brohus et al., 2004, describes the procedures for the integrated design process with an "assessment concept". Below is a short summery on how the assessment concept works.

The concept works on two levels. The first and most "simple" level, the **concept design level**, is applied to get a fast overview and intelligent suggestions of alternative building designs. This level will consist of guidance for scanning, coarse methods, principles, catalogues etc, that will help to give intelligently design suggestions of the building without doing any detailed simulations. The suggestions are sketches/scenarios of the building design.

This pre design level consists of parameter studies for net heat and cooling use during one year for a reference building. Parameter studies for indoor climate where different cases are studied, day-night, winter-summer etc. Also different cooling (heating) techniques will be studied as free cooling, district cooling, cooled ceilings etc. Input from these parameter studies will together with installation energy effectiveness and choice of energy sources give an estimation of the Eco-factor. The results give guidance's of how different parameters affect the indoor climate, the energy consumption and the Eco-factor for a reference case, and will not tell directly how these parameters will influence a specific building.

The second and "advanced" level, the **detailed design level**, is aimed for the consultants to do detailed designs of a few chosen cases. This will be a method on how to systematically explain how to do advanced simulations, and suggestions of simulation tools to use.

Each level consists of two phases, a **design phase** and an **assessment phase**. In the pre design phase is the building designed by two or three sketches going into more detail on a chosen overall solution in the advanced design phase. These building suggestions are assessed according to the Eco-factor method. A high score will indicate that the building has a good indoor climate, low environmental impact or use renewable energy sources, or a combination of these factors. The concept may recommend that a lifecycle cost analyse should be performed for the building design suggestion.

If the suggested building design and technical solution give satisfactory results in the assessment phase the concept will lead to the next level. If not, the process will go back to the design phase. This process will continue in an iterative way until a desirable Eco-factor is achieved for a suggestion with reasonable costs. The concept can be summarised as in the illustration in Figure 4.9.

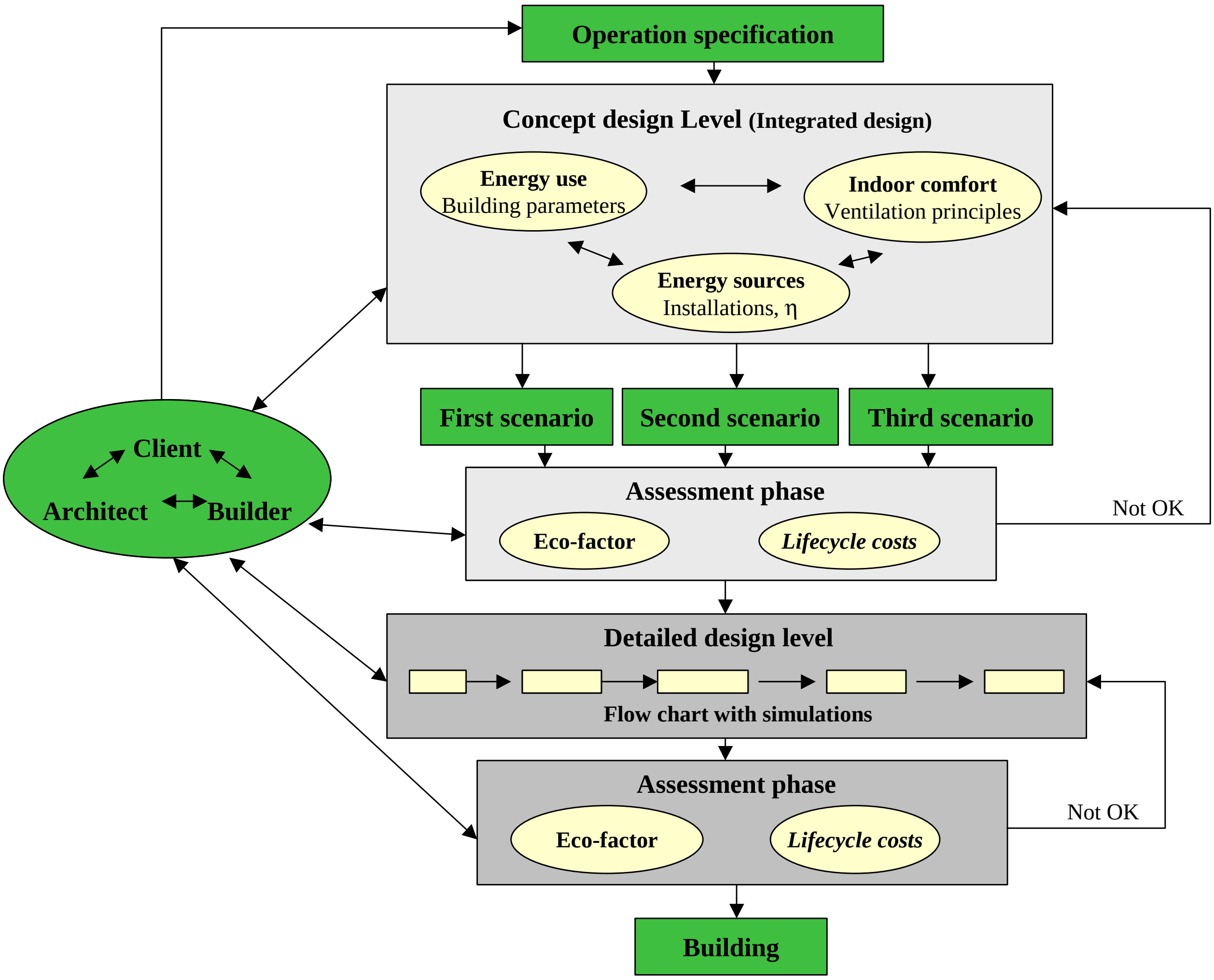

Figure 4.9: Illustration of the assessment concept

The assessment concept and the calculation of the Eco-factor require information on net energy use and indoor climate. The level of detail depends on the stage of the design process as indicated in Figure 4.9.

5. Discussions and Conclusions

The Eco-factor method aims to enable environmental assessment of different energy sources and techniques in the design/planning of energy efficient buildings with low environmental impact and desired indoor climate.

The following **requirement specification** has been settled for the method:

- Primarily consider performance during operation.
- Consider environmental impact from energy use as a core issue.
- Consider indoor climate as a core issue.
- Be constructed in a way so it is possible to add further issues later on.
- Possibility to exclude issues when no information exists
- Use existing evaluation tools/methods as far as possible.
- Use hierarchical structure, starts with a general method with standard data as default values with possibilities to go back and refine the calculations.
- Use priority, local or site-specific data when possible. Be open for the users own assessment basis.
- Easily understandable comparison from 0 – 100%. A high score of the Eco-factor means an improvement compared to average European buildings.
- Easy to visualize and communicate.
- Be transparent with references to data used and clear description of calculations, assumptions and system boundaries.
- Be possible to use in a control system.

One system for whole Europe

A recurring theme in discussions about energy and indoor climate is climatic differences: Should these be reflected through the choice of benchmarks, or of weighting factors? Also, should local building tradition and legislation be incorporated? For instance: Should it be permissible to use more heating and lighting in cold and dark (northern) geographic regions, or to have less strict requirements for thermal comfort in warm and sunny areas?

Granted, there are different climatic conditions in different parts of Europe, which is important for both energy use and indoor climate, see for instance (Bjørn and Brohus, 2003). However, in our view, this should be reflected in the actual design of the building, not in the assessment criteria. Emissions and resource depletion due to energy use are global problems and responsibilities, and there is no obvious reason why some countries should have more right to use energy resources than others.

If building regulations or traditions for building design and construction fail to respond to local climate, this will be reflected in a relatively poor score on the Eco-factor scale. This should encourage the designer to take into account the local climate in the building design, and will assist in pointing out problems that arise when a certain building design, architectural style, or technical solution is “imported” from other climatic zones, as it is often seen.

In this way, it will also become obvious to the building professionals if the national building codes are much different from EU average, and from other national standards, official and unofficial benchmarks and reference cases, etc. This could in an indirect way encourage professionals to compare their results to more strict standards, and perhaps encourage a move towards more uniform national standards based on common EU standards, which in any case is the current development in Europe. The common scale is in our view also advantageous in an EU with an increasingly open building market, where companies in one country wish to export their solutions to other countries.

Limited number of environmental impact categories

Another standing discussion is just which environmental impact categories to include in such a tool as the Eco-factor. It could be argued that the Eco-factor omits many important environmental aspects of buildings, which is obviously true. In this respect we find the tool typology presented in Chapter 1.3.3 particularly relevant. As it is intended, the Eco-factor itself is a "Level 2" tool, meaning that it has the whole building and related processes as the scope of the study, but focused on particular aspects of the design. We have chosen to focus on the coordination of indoor climate and energy related environmental aspects, since this is perceived as a key hindrance for progress. It is theoretically possible to add more impact categories, but we are not so sure it is a good idea, since there is an inherent danger in widening the scope, which is that of loosing the focus on the main points. The only obvious category to include is that of light quality (in the Indoor Climate Eco-factor), but we do not, as yet, have the theoretical foundation for including this in the Eco-factor scoring system, and this will have to be considered in later projects.

Normalisation of energy use

A future improvement could be to include an option for normalisation of energy use by person or person-hours instead of square meters, in order to reflect how well the space and/or time is utilised. This would be relevant in cases where many occupants on a small area require high-energy use for cooling and a high air change rate. Another aspect is that area and energy use per person must be limited in a sustainable society.

In this connection, we see an immediate problem in estimating/collecting data since statistical energy data defined by person are scarce and thereby it is difficult to define the benchmarks. We have not included this possibility for the time being, but acknowledge the potential for including this viewpoint in building design.

Choice of benchmarks

We have had many considerations about the choice of benchmarks.
They have been chosen to define a reference frame, which is "reasonable" and "recognisable", in the sense that they should:

- "Award" actual improvements by giving high scores
- Result in a consistent, easily understandable scale.
- Be based on ISO/CEN standards and statistical data from EU countries

Benchmarks for indoor climate

Special care has been given to the choice of indoor climate benchmarks, since especially the 50% Benchmark is debatable. It could be argued that:

- The indoor climate benchmark scale should be relatively mild, in the sense of allowing more discomfort (for instance category C in CR 1752 (1998) since this will give room for making more energy efficient buildings (larger temperature variations permissible).

- The indoor climate benchmark scale should be relatively strict (e.g. “A” in CR 1752, 1998), by allowing less discomfort, since this will encourage designers to make buildings with improved indoor climate.

In both cases, choosing an extreme value for the 50% Benchmark has the unfortunate side-effect of sabotaging the possibilities for improvements in the other category. Obviously, the Benchmark must be chosen to reflect a reasonably modern standard, but on the other hand not be *too* difficult to obtain in a practical and economical sense. The chosen “category B” from CR 1752 (1998), is as close as we have come to finding an authoritative “standard” indoor climate quality, based on the newest knowledge of the subject, and fulfills our need.

Benchmarks for energy

Since both energy uses and type of energy sources are highly varying within offices in different European regions it has been impossible to define a reference frame where all different regional offices could be represented, at the same time, as design changes should be possible to verify. An office with best possible practice must be the future aim and the upper-limit benchmark of 100% was natural to be represented by an office with no emissions due to energy use.

The second energy benchmark should represent the emission impact of an average European office. It is due to the decision that the reference frame should be suitable for whole Europe and that this point will describe today’s situation. The future goal is to improve today’s average and therefore a broad scale so that improvements could be verified was needed. At the same time there are offices that are performing worse than the average even though their performance could be acceptable when considering outdoor climate conditions, building use, availability of energy sources etc. In order to satisfy both above aspects as far as possible the benchmark for the average European office has been chosen to 25%. This means that an office with an Energy Eco-factor between 0-25% has higher emission impact than the European average but that it still can be better than average in specific areas or for specific purposes.

The Energy Eco-factor cannot be above 100%. Theoretically that would mean that the building would consume emissions directly or indirectly by producing energy for applications that otherwise would have used energy sources with higher emission impacts.

The method does not consider Eco-factors below 0%. A new or retrofitting design of a building that has an emission impact that is considerable lower than the fixed point for the European average is not acceptable and will therefore not reach a score in the Energy Eco-factor method. It should be possible by an intelligently design to reach a score for all buildings independent on limitations due to outdoor climate conditions, building use, building location, building original design, availability of energy sources etc.

The Eco-factor indicates that the office is better or worse than a typical European office but it does not say that the building performs well or if it has potential for improvements. This must be evaluated while considering the office specific outdoor climate conditions, building use, building location, availability of low-emission-impact energy sources etc. By introducing other standard offices for typical or best practice within the same building category to the scale, it can be evaluated if the considered office has a reasonable Eco-factor or if it easily could be improved.

Other national standards, including the designers own, could also be shown relative to the chosen standard. In this way, it is possible to compare for instance national benchmarks to other buildings in Europe, or compare buildings across countries, on a common scale.

Weighting

A total Eco-factor that includes assessment of both energy related environmental impact and indoor climate, requires a weighting between subcategories. Since, there are no scientific weighting rules the weighting must be based on a subjective assessment. In order to do the weighting as objective as possible the Eco-factor method clearly describes how the weighting is performed and gives default values for the weighting in three different ways:

1. Equal weight when no scientific base for assessment is available. Categories on the same level of importance are given equal weight.

2. Use weighting factors from recognized environmental assessment methods. It is recommended to do the assessment for several different recognized environmental assessment methods, which might illustrate the uncertainty in this step. If all methods are showing nearly the same result it will strengthen the final assessment.

3. Dominating weighting between subcategories on a level that cannot be added since failure on one category means that the whole solution has failed (indoor climate, local discomfort). The sub indicator with the lowest score defines the final score on each level.

4. Possibility to include user-defined weighting factors for e.g. reflecting company polices in the assessment.

Advantages of method

The Eco-factor method has the following advantages:

- A consistent and easily understandable scale for comparing buildings.
- Supports an iterative procedure, useful for “integrated design”.
- Easy to adopt system to take care of more issues, or divide into sub-issues (based on the availability of data), while keeping the same fixed scale.
- Not an advantage to focus on single issues, i.e. holistic approaches is preferable to obtain high scores.
- The “ranking” method can assist the designer by highlighting possibilities for improvement.
- Will reward buildings that respond to local conditions, rather than just copying other solutions. This is an effect of using results oriented indicators. Energy use, energy sources, and indoor climate indicators must by necessity be either calculated on the basis of local climate and energy resource data.

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Appendix

Other related building environmental assessment methods and software tools

In Chapter 1.3.2 the most relevant related assessment methods are described. Below are some more existing assessment methods, which include a database for lifecycle inventories and weighting factors of environmental effects. Some of the methods are employed in PC software. Many more software tools and methods than those listed below exist, often in national variations.

BEPAC

Building Environmental Performance Assessment Criteria—developed in 1993 by the University of British Columbia.

BEES

The U.S. National Institute of Standards and Technology (NIST) Green Buildings Program began the Building for Environmental and Economic Sustainability (BEES) project in 1994. The purpose of BEES is to develop and implement a systematic methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance based on the decision maker's values. The intended result is a cost-effective reduction in building-related contributions to environmental problems.

ECO QUANTUM

Eco-Quantum is an Dutch LCA based computer based tool which calculates the environmental effects during the entire life cycle of the building from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse. This includes the impact of energy, the maintenance during the use phase and the differences in the durability of parts of the construction related to the life span of the building. Eco-Quantum also takes into account the possibility for selective demolition, recycling and product reuse. http://www.ivambv.uva.nl/uk/producten/product7.htm

EcoEffekt

EcoEffect (from Sweden) is a method to calculate and assess environmental loads caused by a building during an assumed lifetime. It is developed for persons who plan, manage or use the built environment and need information about the environmental loads associated with it. Energy use, Materials use, Indoor environment, Outdoor environment and Life cycle costs are areas treated separately in the analysis. The assessment is based on life cycle analysis (LCA) for energy and materials and on criteria for indoor and outdoor environment. The result is presented as an environmental profile for each area with about 10 bars showing the environmental loads for different impact categories. A method to aggregate this information into a few environmental load numbers for every area has been developed to simplify a comparison between elements, buildings or estates. For use of energy and materials load numbers for emissions, waste and natural resource consumption have been elaborated. The environmental conditions indoors and out of doors on the estate are described by the load numbers for ill health, discomfort, biological diversity and biological productivity. Glaumann (1999, 2000). http://www.bmg.kth.se/Bob/EcoEffect/hemengel.html

Athena

Athena TM is an LCA oriented program with a large database of building materials and their environmental effects developed in Canada. It takes into account the environmental effects of:

- material manufacturing, including resource extraction and recycled content
- related transportation
- on-site construction
- regional variation in energy use, transportation and other factors
- building type and assumed lifespan
- maintenance, repair and replacement effects
- demolition and disposal
- operating energy emissions and pre-combustion

Using preset building assembly dialogues, a conceptual building design can be entered. Specific to your geographic region, you can see the cradle-to-grave implications of the design in terms of:

- embodied primary energy use
- global warming potential
- solid waste emissions
- pollutants to air
- pollutants to water
- natural resource use

Trusty et al. (1998), http://www.athenasmi.ca/

EQUER

The life cycle simulation tool EQUER (from France) is based upon a building model structured in objects, this structure being compatible with the thermal simulation tool COMFIE. The functional unit considered is the whole building over a certain duration. Impacts due to the activities of occupants (e.g. home-work transportation, domestic waste production, water consumption) may be taken into account according to the purpose of the study: this possibility is useful e.g. when comparing various building sites with different home-work distances, waste collection system, water network efficiency etc.
http://www-cenerg.ensmp.fr/english/themes/cycle/html/15.html

ECO points + ENVEST program

The ECO points methodology—originally developed in Switzerland and Holland; bases its measurements on the symptoms of environmental impact (i.e., pollution load). A UK Ecopoint is a single unit measurement of environmental impact. A UK Ecopoint score is a measure of the total environmental impact of a particular product or process expressed in units (ecopoints). It is calculated in relation to impacts on the environment in the UK and therefore applies to UK activities only.

Ecopoints describe all the environmental impacts arising from a product throughout its life cycle. They capture the relative importance which industry and society assigns to those environmental impacts.Ecopoints are calculated from a defined range of Life Cycle Assessment (LCA) data. LCA is an internationally established assessment method and Ecopoints are based on the published UK methodology for construction materials; the BRE’s Environmental Profiles.Characterised LCA data is normalised, according the impact of 1 UK citizen and weighted according to an industry consensus exercise, carried out for the UK government. ENVEST: http://www.bre.co.uk/envest

Ecoprofile

Ecoprofile is a top down method for environmental assessment of existing office buildings. It consists of three main areas: Outdoor environment, Use of resources and Indoor environment focussing on energy flexibility and efficiency, use of hazardous materials (PCB, asbestos etc.). Each of the main areas has 4-6 sub-areas with a total of approximately 90 parameters assessed within these areas. Each sub-area is weighted. The method is based on the use of standardized schemes, questionnaires and reports to minimize the work of assessment and this makes it is easy and cheap to use. The method has been under development since 1995, but has been operative since autumn 1998. At present the method covers only existing office buildings, but work is going on to adapt the method for dwellings.

EcoProP

EcoProP is a requirements management tool, consisting of:

- A generic classification of building properties (VTT ProP®)
- Reference data about environmental requirements and their target values
- Information on relevant verification methods
- Automated procedures to scan requirements profiles and to form a design brief.

The focus is in forming a good design brief resulting in environmentally sound design, construction and operation of buildings. Therefore the method concentrates on specification of environmental protection criteria (Efficient use of Natural Resources, Control of Environmental Pollution, efficient Land Use, maintaining Biodiversity).
http://cic.vtt.fi/eco/e_ecopro.htm

LISA

LISA (LCA in Sustainable Architecture) is a streamlined LCA decision support tool for construction. It was developed in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design.

LISA is designed to: Help identify key environmental issues in construction. Give designers an easy to use tool for evaluating the environmental aspects of building design. To enable designers and specifiers to make informed choices based on whole of life environmental considerations; ie life cycle analysis. http://www.lisa.au.com/

LCACALC

This program, developed in Denmark, has collected data for different building components. The data are lifecycle energy use data that consider energy use for production of building material, construction and demolition as well as transportations. Together with a program that calculates the building's operation energy can the building's energy related environmental impact be calculated and evaluation of different alternative building designs can be done. The results are mainly showed as use of the energy sources, coal, oil and natural gas and their related environmental impact as emissions of $CO_{2,}$ NO_x and SO_2. The program is intended for architect and engineers (Traberg-Borup, 1997). The method is described in Dinesen et. al, 1997.

Petersen et al. 1998 has showed how the program LCACALC can be used together with the EDIP-method (Wenzel et al., 1997a och 1997b). The report has a characterization and weighting of the natural resources oil and natural gas. This work has since extended into the PC-tool BEAT 2002 (see next item).

BEAT 2002

BEAT 2002 (Building Environmental Assessment Tool) is an LCA based inventory and assessment tool developed at the Danish Building and Urban Research, see Petersen (2002). It is targeted specifically at the building industry for environmental assessment of building products and buildings. At present the program is used by a number of Danish producers of building materials, consulting architects and engineers, technical schools and municipalities, as well as a number of technical schools and universities outside Denmark. BEAT was mainly developed for use during design of new buildings, where it can be used both early and later in the design phase, but it has also been successfully used for retrofitting.

EDIP

The Danish EDIP (Environmental Design of Industrial Products) aims to support industry to design environmentally friendly products. It is both a method and a manual for life cycle assessment of products. The method is supported by a base of data for the assessment of environmental impact and is thus designed as a tool. The intended user is an environmental specialist that cooperates with the product designer in the work of developing more environmental friendly products. The method is focusing on lifecycle assessment within product development but can also be used for applications within other areas (Wenzel et al., 1997a och 1997b).