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Assessment concept for the building design process using the Eco-factor method

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ABSTRACT

During the last years the pressure for energy improvement has increased. However, a one-sided focus on energy efficiency might be introduced at the expense of indoor climate. Therefore, it is essential that energy optimisation is integrated with assessment of indoor climate. A guideline tool with an assessment concept based on the so-called Eco-factor method been developed for an integrated design process.

The approach for the guideline is that the whole energy system, regarding both the building and the technical installations, must be considered in order to achieve energy efficient buildings with good indoor comfort and low environmental impact. This requires an integrated design approach of all building elements with involvement of numerous technical disciplines. Since each building is unique there are no all-encompassing solutions and, therefore, the guidelines aim to describe the way of working to reach the goal. In order to evaluate the successfulness of different energy system solutions in different building design the assessment concept is using the Eco-factor method

The Eco-factor illustrates the impact of two core issues: the energy related environmental impact and the indoor climate. The method consists of an index system based on indicators of physical properties that describes the environmental impact and the indoor comfort on a common score, called the ”Eco-factor”. The external environmental impact part is based on emissions from operational energy use of different energy sources. All emissions during the energy sources’ complete life cycle are considered “from cradle to grave”. The indoor climate part considers aspects that are closely interrelated with energy use, namely thermal comfort and indoor air quality.

The assessment concept includes a recurrent “assessment phase”, where the architect and project-leader discuss different solutions with the client. Different energy solutions are assessed with their influence of the total building performance on energy use and indoor climate. This should prevent that single issues in the design are changed without evaluation of how it affects the total building performance. The Eco-factor method aims to present the evaluation in an easy visible interpretation of the result.

1 INTRODUCTION

The new European Energy Performance of Buildings Directive (EPBD, 2002/91/EC) increases the pressure for energy improvement. However, a one-sided focus on energy efficiency might be introduced at the expense of indoor climate. Therefore, it is essential that energy optimisation is integrated with assessment of the building performance regarding indoor climate and the energy related impact of the external environment. In order to achieve a building with high performance it is important to consider the whole energy system, regarding both the building and the technical installations, during the complete design process through the stages of initial ideas, design, construction, commissioning and operation. It requires an integrated design approach of all building elements with involvement of numerous technical disciplines. Since each building is unique there are no all-encompassing solutions and, therefore, an assessment concept for the building design process has been developed. The guideline aims to describe the way of working to reach the goal and the so-called Eco-factor method is used for visualisation of the buildings performance.

The guideline has been developed within an EU-project called IDEEB (Intelligently Designed Energy Efficient Buildings) during 2002-2004. The concept is thorughly described in Bjørn et al., 2004 and Brohus et al., 2004, and summarized in Wahlström and Brohus, 2005.

2 DESCRIPTION OF THE ASSESSMENT CONCEPT

The concept works on two levels, see Figure 1. 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 consists of guidance for scanning, coarse methods, principles, catalogues etc, that will help to provide intelligently design suggestions of the building without doing any detailed calculations. 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 of the indoor climate are performed where different cases are studied, day-night, winter-summer etc. Also different cooling (heating) techniques are studied like free cooling, district cooling, cooled ceilings etc. Input from those parameter studies will together with installation energy effectiveness and choice of energy sources provide an estimation of the Eco-factor. The results give guidance on how different parameters affect the indoor climate, the energy consumption and the Eco-factor for a reference case. They do not specify directly how those parameters influence a specific building.

The second and “advanced” level, the **detailed design level**, is aimed for the consultants to investigate detailed design solutions of a few chosen cases. This part comprises methods on how to systematically explain how to do advanced simulations, and suggestions of simulation tools.

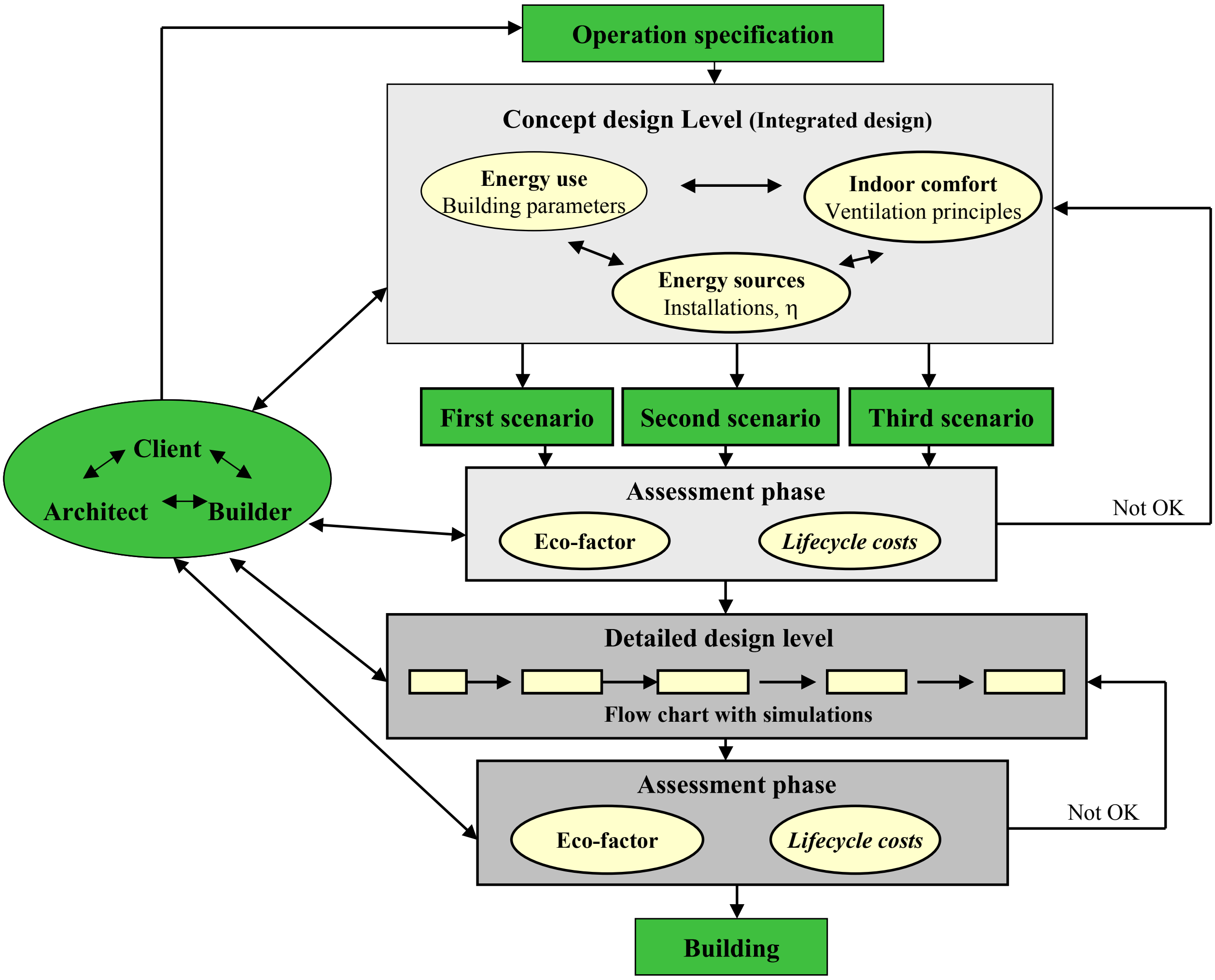

Figure 1: Illustration of the assessment concept

Each level consists of two phases, a **design phase** and an **assessment phase**. In the pre design phase the building is designed by two or three sketches going into more detail on a chosen overall solution in the advanced design phase. Those building design suggestions are assessed according to the Eco-factor method. Apart from architectural, technical and environmental issues, economic planning must always be made in parallel, meaning that life cycle costs must be calculated as part of the design process.

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 continues in an iterative way until a desirable Eco-factor is achieved for a suggestion with reasonable costs. The concept can be summarised as illustrated in Figure 1.

3 DESCRIPTION OF THE ECO-FACTOR METHOD

The Eco-factor assists the design process by providing a simplified and standardised output explaining in a simple way the overall environmental performance to the decision-maker (e.g. the owner and/or the architect), who can then better concentrate on making wise decisions, instead of wasting valuable effort trying to understand and evaluate complex technical details.

Determination of the Eco-factor requires input data from two core environmental impact categories, which in any case are calculated or by other means assessed as part of the building design process. The building designers have different needs at different stages of the design process and accordingly the requested level of detail of input data increases with the progression of the iterative design process (Figure 1). The input data can be calculated using different energy and indoor climate simulation tools but may also in many cases be calculated by the same calculation tool(s), since they require more or less the same underlying information for the theoretical models.

For this reason the Eco-factor method is defined so that input can be based on both simple and advanced calculations in early and later phases of design, respectively, while still delivering the same output, see Figure 2.

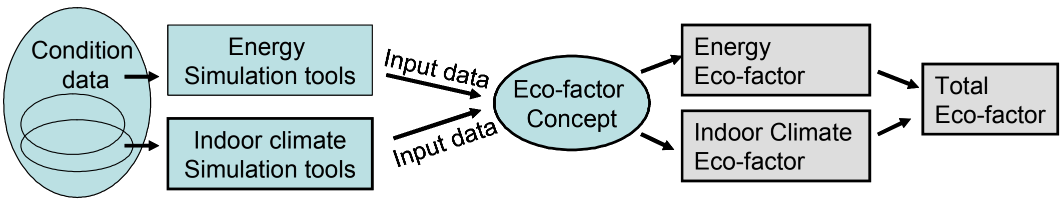

Figure 2: Calculation of the Eco-factor requires input data from existing energy and indoor climate simulation tools. The required quality and detail of the energy and indoor climate simulation tools increases as the design progresses, while the Eco-factor method remains the same.

The Eco-factor illustrates the impact of two core issues:

- Global environmental impacts
  - Energy use from different energy sources during operation
  - Emissions to the atmosphere during the life cycle of the energy source
- Indoor environment
  - Thermal comfort
  - Atmospheric comfort, IAQ

The method consists of an index system based on indicators of physical properties (namely operational energy use, air-borne emissions, plus indoor temperatures, velocity, and concentration fields) and weighting factors from the literature that describes the environmental impact and the indoor comfort in a score on a common ”scale” from 0-100%, called the ”Eco-factor”.

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.

3.1 The Energy Eco-factor

All use of energy results in some kind of environmental impact. The Eco-factor method considers the most important environmental impacts in shape of emissions to the air. Apart from impacts from emissions, energy use affects the use of natural resources, exploitation of ground and the production of waste, which are not considered in the Eco-factor method presented here. The reason for this choice is to provide a tool that considers the main environmental impact without being forced to perform a full LCA that may require substantial time, effort and expert knowledge. Since political or organisational priorities may sometimes be focused on aspects other than airborne emissions, such as radioactive waste, the Eco-factor method has been extended with a so-called low-priority factor which is described in Bjørn et al., 2003. The Energy Eco-factor is based on environmental impact due to emissions to air from energy use and can be calculated with the indicators:

- Specific energy use for each energy source (kWh/[year, m^2])
- Emission impact from energy sources (mg/ kWh)

Energy use for each energy source

A comparison between different energy solutions should be made for the same boundary conditions. The energy input for each energy source in the Energy Eco-factor is defined as annual energy use for operation per treated useable area, i.e. the building's inside area that is heated or cooled. Only energy applied for building operation is considered, since studies show that it accounts for the major part of the total life cycle energy use. Less than 20 % is used for manufacturing of building materials, transportation of materials, building, maintenance and demolition (Cole and Kernan, 1996: Németh Whinter, 1998: Adalberth, 1999: Ståhl, 2002). For low-energy houses, this part will of course increase relatively. Efforts to decrease the environmental impact from energy used in the operational phase will therefore have the most significant impact.

Emission impact from energy sources

This aspect of the method considers the environmental impact of emissions to air during each energy source's complete life cycle (extraction, production, transportation and combustion). The emissions considered are CO_2, SO_x, NO_x, CH_4, CO, N_2O, NmVOC, NH_3 and fine particles, which will affect the environment by their impacts on global warming, acidification, photochemical ozone formation, eutrophication and emissions of fine particles. Established environmental assessment methods are used in order to weight the emissions into one common score. Examples are EPS (Steen, 1999 and Ryding et al. 1998) or Eco-indicator 99 (Goedkoop and Spriensma, 2000), which both have defined assessment indices for each considered emission. The indices describe the magnitude of the environmental effect and are set by considering the emission's environmental impacts in terms of its effects on global warming; acidification and its associated impact on human health and the ecosystem's quality (see Bjørn et al., 2003).

Indicator of environmental impact

Each established environmental assessment method has its own indicator system with its own Indicator unit, e.g. ELU (Environmental Load Unit) or kg CO_2-equivalent, and is calculated from;

$$I = \frac{\sum_{i}^{n}\left(\sum_{j}^{n}(e_j \cdot index_j) \cdot Q_i\right)}{A} \qquad \textit{Equation 1.}$$

where:

I = specific indicator for the emission impact (Indicator unit/[m^2, year]),
e = emission (kg/kWh),
index = assessment index decided by the environmental assessment method (Indicator unit/kg),
Q = annual net energy input (kWh/year), A = treated useable area (m^2), i = energy source and
j = emission substance.

Definition of the Energy Eco-factor

The Energy Eco-factor is intended to provide an easily understandable grading from 0 – 100%: see Equation 2. This is done by using two fixed well-defined benchmarks, which are chosen in order to provide a reasonable, meaningful, common reference frame suitable for European offices:

- An Energy Eco-factor of 100 % would 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 % represents the emission impact of an average European office. This point is chosen in order to provide a broad scale (25 – 100%) for offices that have made improvements compared with the average. The average European office is based on figures collected in a survey of EU member states about energy consumption in the service sector (European Communities, 2002): see Table 1.

$$\varepsilon_E = 100 - \frac{75 \cdot I}{I_{25\%}} \qquad \textit{Equation 2.}$$

ε_E = 100 for $I < 0$;

ε_E = 0 for $I > 1.333 \cdot I_{25\%}$

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, second benchmark (Indicator unit/[m^2, year]).

An Energy Eco-factor between 0-25% shows that the emission impact is higher than the European average, although it can still be better than average in specific areas or for specific purposes due to dependence on outdoor climate conditions, building use, current practice, availability of energy sources etc. A high score of the Energy Eco-factor means that the building is energy-efficient and/or is using the right energy sources. A low score shows that the building is using unnecessarily much energy and/or is using energy sources that should be avoided. The method does not consider scores below 0% (i.e. energy production).

Table 1: Definition of an 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 (IEA, 2002)

3.2 The Indoor Climate Eco-factor

A high level of discomfort in the indoor climate is perceived as a serious problem by millions of people all over the world both regarding thermal comfort and indoor air quality (IAQ). As to IAQ the World Health Organisation (WHO) has established the generic name: Sick Building Syndrome. Apart from the obvious health and comfort reasons for providing an acceptable indoor environment, a suitable indoor climate is by nature one of the main points of making buildings at all. Furthermore, the indoor climate has a significant impact on the mental and physical abilities of people. When people are not comfortable, their performance deteriorate (Seppänen and Fisk, 2004). The Indoor Climate Eco-factor considers indoor climate aspects that are closely interrelated with energy use:

- Thermal comfort => temperature range => heating, cooling
- Indoor air quality => ventilation => electricity

Air quality and thermal comfort are reflected in terms of sensory perception (expressed in a negative sense as “degree of dissatisfaction”). The Indoor Climate Eco-factor applies a similar “two benchmark approach” like the Energy Eco-factor:

- An Indoor Climate Eco-factor of 100% equals “fewest possible dissatisfied” (best possible benchmark), which are found in ISO 7730 and CR 1752.
- An Indoor Climate Eco-factor of 50% score equals a “normal” percentage of dissatisfied persons, which is represented by the “B” or medium level of expectation from CR 1752 (1998). CR 1752 operates with three pre-defined levels of expectation: A) High, B) Medium, and C) Moderate.

Thermal comfort

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 draughts, vertical air temperature differences, radiant temperature asymmetry and warm or cold floors. For the purposes of building design, comfort is defined negatively as the absence of any form of thermal stress. The definition of thermal comfort follows the established guidelines of ISO 7730 (1991), using PPD (Predicted Percentage Dissatisfied) as an indicator for overall thermal balance, and PD (Percentage Dissatisfied) for local thermal discomfort - except for draughts, which uses ”Draught rating” (DR). Thermal comfort is divided into:

- Overall thermal comfort (PPD).
- Local thermal comfort:
    - Draught rating (DR),
    - Vertical air temperature gradient (PD),
    - Radiant temperature asymmetry (PD),
    - Warm or cold floor (PD).

Environmental parameters for calculation of overall thermal balance include operative temperature, mean air velocity and relative humidity, while human parameters include activity and clothing. The score function for overall thermal state (PPD) is shown as an example in Figure 3. The local thermal discomfort issue radiant temperature asymmetry can be determined by measuring or calculating surface temperatures for the internal surfaces in a room. The percentage dissatisfied (PD) indicator for defining the score can be found in the ISO 7730 standard with surface temperatures as input ($Ci = 100\text{-}10 \times PD$). In a similar fashion, score functions have been devised for the remaining local thermal discomfort indicators:

Draught rating: $Ci = 100 - 2.5 \times DR$

Vertical air temperature difference: $Ci = 100 - 10 \times PD$

Warm or cold floor: $Ci = 100 - 12.5 \times (PD - 6)$

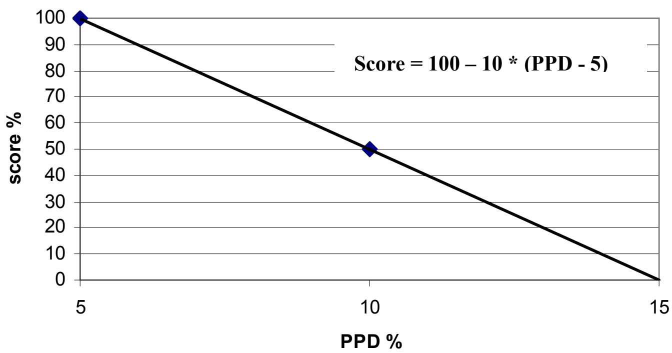

Figure 3: Score function for overall thermal state of the whole body using the PPD indicator. The upper benchmark is chosen as 5% PD, since it is practically impossible to achieve better results in groups of more people, due to variation of thermal preferences in population.

Indoor Air Quality (IAQ)

Atmospheric comfort is the sensory perception of the indoor air. For design purposes, and thus for classification, the quality of the air can be described with one of two different optional indicators.

- Percentage Dissatisfied (PD) due to dissatisfaction with the perceived air quality, with bioeffluents from a person (measured in the unit olf) being the reference standard. Building materials, ventilation ducts, etc. are assessed in this way, too, indirectly by naïve or trained sensory panels (Fanger, 1988).
- Concentration of CO_2 in the air. This is a good indicator of human presence, and can also be used as input for control systems. However, if substantial pollutants (apart from people) are involved, this indicator will not be adequate. Dissatisfaction (PD) is described in CR 1752.

Score function for IAQ: $Ci = 100 - 3.3 \times (PD - 5)$

3.3 Weighting into total Eco-factor

The Eco-factor method has two main impact categories (energy-related environmental impact and indoor environment), which should be weighted together into one score. In several other related assessment tools, such as GBTool, LEED or BREEAM, the energy part is considered somewhat more important than indoor climate. The focus and aim of the Eco-factor is that good indoor comfort should not be inadequate as a result of too ambitious energy optimisation, and therefore the weighting is set equal to 50%.

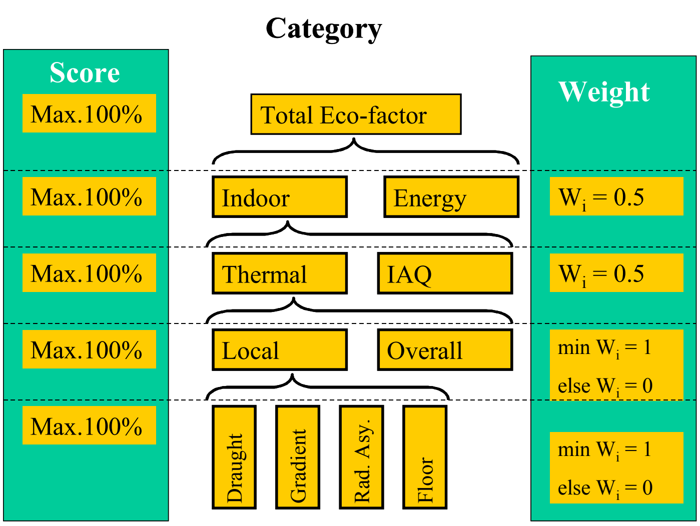

Figure 4: Weight factors used to add subcategories. $W_i = 0.5$ means that each category is weighted by 50%. "min $W_i = 1$, else $W_i = 0$" means that the subcategory with minimum score is weighted with 100%, all other categories are weighted with 0%, so that the worst performing subcategory defines the level (e.g. dissatisfaction caused by serious draught is not arbitrarily reduced by a satisfactory floor temperature).

The overall score for indoor climate is provided by weighted addition of the score for the "Thermal comfort" and "Indoor Air Quality" subcategories, with equal weighting (50%). The reason for this is that the categories are very different in their physical nature and at present no substantial scientific reason exists for using different weight factors.

The general idea of the ISO 7730 standard (and CR 1752) demands that all issues must be addressed satisfactorily, which means that if one objective fails, then the whole solution has failed. For this reason, the two lowest levels in the hierarchy (local and overall thermal comfort) have a weighting where the score on each level is defined by the sub-indicator which achieves the lower score. This will assist in quickly identifying problems, instead of obscuring problems by adding several subcategories to an overall score. The weighting for the final Eco-factor is illustrated in Figure 4.

3.4 Excel-spreadsheet based tool

To be of any practical use, the Eco-factor must be able, relatively quickly, to provide a visual and easily understandable representation of the environmental effects of different alternative choices. The Eco-factor tool, which is Excel-spreadsheet based, has therefore been created with a database of "default" data. The tool assists with default data of eco-profiles of typical energy sources and weighting factors for different assessment methods and the user does not need to supply these input. An example on how the results are presented is shown in Figure 5.

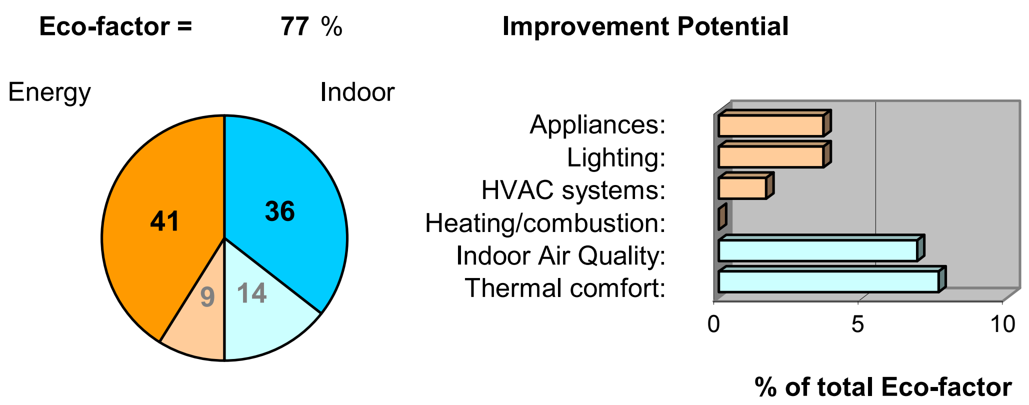

Figure 5: Example of how the result of the Eco-factor is illustrated. On the right the so-called "Improvement potential" is shown, which reveals the specific parts of the design that are not performing well or where it is possible to achieve more "points" (lighter colours in left pie chart) to improve the Eco-factor.

4 EXAMPLE OF THE USE OF THE ECO-FACTOR METHOD

As an example on the use of the Eco-factor method in the design process, the design of the Bang & Olufsen Headquarter in Denmark is considered, a building which has been thoroughly investigated during the design phase.

Bang & Olufsen required an office building of high quality and a minimum of technical installations, which should be simple and hidden. The building is specifically designed for hybrid ventilation. Natural ventilation has been highly prioritized due to cheaper and more discreet installations together with improvement of indoor comfort (air quality). Fan asistance is available when the natural driving forces are insufficient. The design was focused on indoor climate, functionality, initial investments and energy reductions. In the design stage of the ventilation system the architects and engineers took into account both the buoyancy related driving forces as well as the wind induced driving forces. The design team, the client and the main contractor had a thorough co-operation to optimise the initial cost of the building.

As can be seen in Figure 7 the building obtains a relatively high score on the Eco-factor scale, mainly due to a high score on indoor climate. It is notable that the indoor climate was thoroughly considered during the design phase, and this may be a reason for the achievement of better-than-average scores in indoor climate categories. This is the result of having indoor climate as a focal point of design besides the energy consumption. More resources than usual have been put into analysing airflows and dynamic temperature calculations, and validation measurements have been carried out and reported.

Figure 6: B&O Headquarter in Denmark. Terrain: Rural, flat; Climate: Marine west coast climate, windy

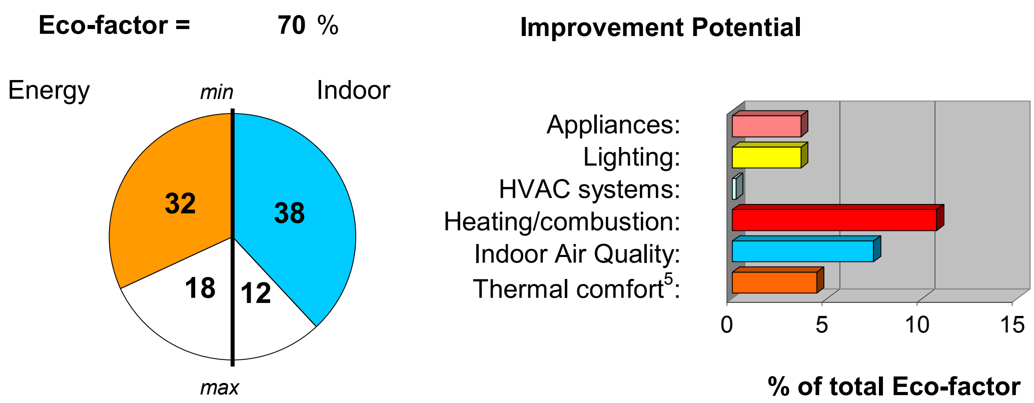

Figure 7: Eco-factor for the design of the B&O Headquarter. The filled part of the pie chart shows the score while the remaining part shows the ”missing” points (the points that could be improved in order to reach full score). The ”missing” points are found in the improvement potential chart at the right where it is possible to see where one should focus effort in order to improve the design.

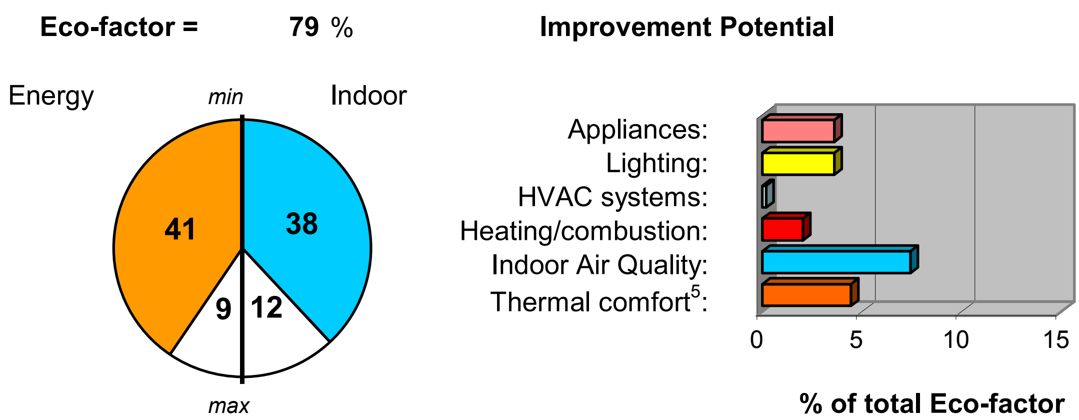

Figure 8: Eco-factor for the design of the B&O Headquarter with change of heating source to biofuels instead of natural gas.

The building is very successful regarding savings in electricity for HVAC, which is a natural result of the hybrid ventilation system. However, the energy use for heating and other electricity is somewhat dissappointing from a Danish point of view, since an average new Danish office building would in fact perform better. But the total result is still better than average on a European scale, which reflects the fact that Denmark has some of the most demanding energy regulations in Europe, more than a desire from the owner to have a highly energy-efficient building. In order to improve the Eco-factor score it could be beneficial to change heating source from natural gas. If it could be based for instance on bio fuel – perhaps in a small electricity cogeneration scheme, which is presumably viable regarding economy and resources in this area – the final result could be substantially improved. Figure 8 shows that the score is increased with 9 % and the improvement potential shows that in order to further improve the score one should put efforts in considering indoor air quality (like increased air change rate and/or improved ventilation effectiveness).

4.1 Application

The assessment concept is intended to be an integral part of new design guidelines where architects and engineers should be able to obtain a quick overview of the effect of changing key parameters such as room height, air change rate, internal heat loads, control strategies, etc. in rapid iterations, showing the potential for improvements in energy-related emissions and indoor climate. The improvement potential is visualized by the Eco-factor method which aims to assist the architects and engineers to easy communication with the client. The assessment concept should be possible to use with different contracts/organizations but require a close cooperation between different parties in different stages of the process (Nordström, 2004). The important part in the assessment concept is the recurrent “assessment phase”, where the architect and project-leader discuss different solutions with the client. Here, different energy solutions are assessed with its influence on the total building performance.
This should prevent that single issues in the design are changed without evaluation of how they affect the total building performance. The Eco-factor method aims to present the evaluation in an easy visible interpretation of the result.

During development the guideline has been tested theoretically in case studies of newly built energy efficient buildings (Bjørn and Brohus, 2003). It has also been tested in pre-design of a new construction in Gothenburg and a retrofit of an office building in Bristol. Unfortunately, the market situation for the construction of office buildings changed so that the constructions have not been carried out. The guideline is now ready to be tested in practice for improvements and extensions.

5 CONCLUSIONS AND DISCUSSIONS

The assessment concept for the building design process with the Eco-factor method has been developed considering the following requirement specification:

- The ability, relatively quickly, to provide a visual representation of the environmental effects of different alternative choices, which is easy to understand and to communicate.
- It simplifies the decision process to consider only one “scale”, instead of having to consider kWh/m^2, PPD, PD, DR etc. and discussing how much significance to attribute each result.
- Constant format of output, meaning the same resulting indicators are used regardless of the calculation models used for energy and indoor climate.
- Supports an iterative procedure, useful for “integrated design”.
- No advantage in focusing on single issues, since poorly performing parts of the design are penalized.

- The "ranking" method can assist the designer by highlighting potentials for improvement.
- Will reward buildings that respond to local conditions, rather than just copying other solutions. This is a result of using results-orientated indicators. Energy use, energy sources and indoor climate indicators must be calculated either on the basis of local climate or of energy sources.
- Can be used both in the design phase and for improving building operation, e.g. by decisions made by the control system of the building, since indicators are measurable.

The guideline is developed by primarily considering design of European office buildings and should cover warm, moderate and cold European climates. With small adjustment it should be possible to use it for the design of any kind of building. The assessment concept is using an integrated approach with involvement of all disciplines. This makes the guideline very suitable for integration of responsive building elements and it is now ready to be tested in practice.

6 ACKNOWLEDGMENT

The Eco-factor method has been developed as part of the EU IDEEB (Intelligently Designed Energy Efficient Buildings) project, which is of interdisplinary character with experts from different parties of the building industry from Sweden, Denmark, The Netherlands, the UK and Greece.

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