An Eco-factor method for assessment of building performance

Å. Wahlström, Ph.D.,
SP Swedish National Testing and Research Institute, Sweden;
asa.wahlstrom@sp.se www.sp.se

H. Brohus, Ph.D.,
Aalborg University, Denmark ;
hb@bt.aau.dk www.aau.dk

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SUMMARY:
The new European Energy Performance of Buildings Directive will increase the pressure for energy improvement but a one-sided concentration on energy efficiency might be introduced at the expense of indoor climate. It is, therefore, essential that energy optimisation is integrated with assessment of indoor climate and there is a need of an assessment tool that evaluates the performance of different energy system solutions. Therefore, an Eco-factor method has been developed that aims to assist architects, engineers, builder and clients in the decision process of office building design.

The Eco-factor illustrates the impact of two core issues: the energy related environmental impact and indoor climate. The method consists of an index system based on indicators of physical properties that describes the environmental impact and the indoor comfort in a common score, called the "Eco-factor". The outdoor 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, thermal comfort and indoor air quality.

1. Introduction

The new European Energy Performance in Buildings Directive (EPBD, 2002/91/EC) will require energy simulations and declarations of a building's energy performance, which in their turn will bring new demands for energy improvements. However, improvements of energy performance and/or its related environmental impact are often introduced at the expense of indoor climate. To avoid the indoor climate problems that are all too often seen in contemporary office buildings, it is essential that energy optimisation is integrated with assessment of indoor climate, and there is a need for an assessment tool that evaluates the performance of different energy system solutions.

Problems in office buildings are often related to the design and control of the indoor environment and of the building as an energy system. It is important to bear in mind that the indoor climate and energy use are often interconnected, since such factors as internal and external heat loads, temperatures and air change rates affect both energy use and indoor comfort. Furthermore, it is not the energy use in itself that is important to consider but the possible environmental impacts of each energy source, in order to place the building in the wider environment of its effect on global warming and other environmental effects.

The EU IDEEB (Intelligently Designed Energy Efficient Buildings) project has included development of an assessment concept that can be useful for assisting building designers in finding solutions to these problems (Brohus et al., 2004). The assessment is intended to be an integral part of new design guidelines for office buildings, which aim to achieve energy-efficient buildings with good indoor comfort and low environmental impact. It is the intention that 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 either energy-related emissions or indoor climate, and at the same time highlighting perhaps unforeseen dangers of compromising indoor climate in order to improve the energy performance, or vice versa.

A so-called Eco-factor is used to assist the evaluation of the energy-related environmental impact and indoor climate. The main purpose of the Eco-factor method is to provide a means of assessment between alternative choices of energy design of European office buildings, and to optimise the use of different energy sources in the operational phase while at the same time ensuring a satisfactory indoor climate, i.e. a holistic approach. This paper aims to describe the Eco-factor method, and to show an example calculated with the Eco-factor tool, which is an Excel-spreadsheet tool programmed with the Eco-factor method.

2. The Eco-factor method

The primarily objective of the Eco-factor is for use in the design phase, even though it also can be used for indoor environment monitoring and optimisation of energy sources in the operation phase. The Eco-factor aims to assists by providing an easily understandable representation of the environmental effects of different alternative choices. It has two core environmental impact categories:

- 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

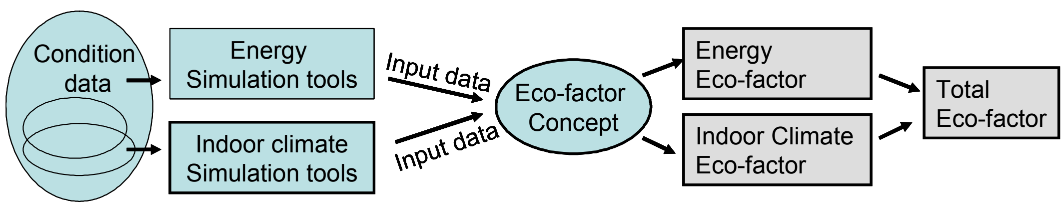

FIG. 1: Calculation of the Eco-factor requires input data from existing energy and indoor climate simulation tools.

Determination of the Eco-factor requires input data for both categories, which requires the use of existing energy and indoor climate simulation tools. These input data will, in any case, be calculated or otherwise assessed as part of the building design process, and in many cases can be calculated by the same calculation tools, since they require the same underlying theoretical models with basic data of indoor and outdoor temperatures, air change rates, etc. The Eco-factor method seeks to compile the overall effect of these efforts, and to create an overview by simplifying and standardising the output to the decision-maker (e.g. the owner or the architect), who can then better concentrate on taking the best decision, instead of wasting valuable effort on understanding and evaluating technical details. Use of the Eco-factor tool can also act as a reminder to the decision-makers that certain design criteria should be considered even at early stages of the process. The process for calculating the Eco-factor is illustrated in Figure 1. The required quality and detail of the energy and/or indoor climate simulation tools increases as the design progresses, while the Eco-factor method remains the same. Consequently, the quality of the calculated input data increases as well, which is reflected in the Eco-factor. This process is described in Brohus et al., 2004.

2.1 The energy Eco-factor

All use of energy results in some form of environmental impact. The Eco-factor method considers the most important environmental impacts in the form of emissions to air. Apart from impacts from emissions, energy use affects the use of natural resources, exploitation of ground and the production of waste, which will not be considered in the Eco-factor method presented here. Since political or organisational priorities may sometimes be concentrated 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 effect.

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 index describes the magnitude of the environmental effect and is set by considering the emission's environmental impacts in terms of its effects on global warming, acidification etc., 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;

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

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 points, which are chosen in order to give 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 to 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.

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

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]).

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 for 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%.

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)

2.2 Indoor Climate Eco-factor

Sensory perception of indoor climate is perceived as a serious problem by millions of people all over the world, and the World Health Organisation (WHO) has given them the generic name, Sick Building Syndrome. Apart from the obvious health and comfort reasons for providing a suitable indoor environment, it is 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 performances deteriorate. 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”). A similar approach is used as for the Energy Eco-factor:

- An Eco-factor of 100% equals “fewest possible dissatisfied”, which are found in ISO 7730.
- An 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 is shown as an example in Figure 2. 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 ($Ci = 100-10 \times PD$). In a similar fashion, score functions have been devised for the remaining discomfort indicators:

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

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

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

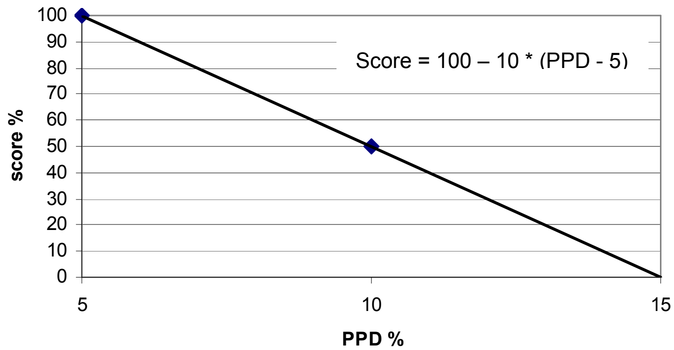

FIG. 2: Score function for overall thermal state of the whole body using the PPD indicator. The upper benchmark is chosen as 5% PD, since it is practically impossible to achieve better results, due to variation of thermal preferences in population.

Indoor Air Quality (IAQ)
Atmospheric comfort is 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.

- Percentage Dissatisfied (PD) due to dissatisfaction with the odour of the air, with body odour from a person (measured in olf) being the reference standard, although building materials, ventilation ducts, etc. can also be assessed in this way by trained sensory panels, see (Fanger, 1988).
- Concentration of CO_2 in the air. This is a good indicator of human presence, and can also be used as an 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: $Ci = 100 - 3.3 \times (PD - 5)$

2.3 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%.

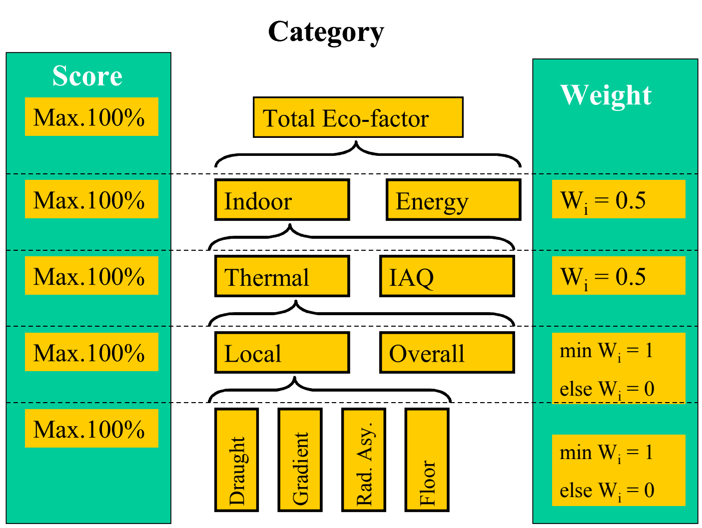

FIG. 3: Weight factors used to add subcategories. $W_i = 0.5$ means that each category is weighted by 50%. "min $W_i = 1$, else $W_i = 0$" means that the subcategory with minimum score is weighted with 100%, all other categories are weighted with 0%, so that the worst performing subcategory defines the level.

The overall score for indoor climate is arrived at 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 there does not seem to be any scientific reason for giving different weight factors.

The general idea of the ISO 7730 standard 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 3.

3. Example of use of the Eco-factor tool

The "Eco-factor" aims to quantify the performance on a common scale from 0-100%, with 100% being "as good as possible", and 0% being below a certain minimum performance, which is defined by benchmarks in relevant impact categories. However, 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. For calculating the Energy Eco-factor, the tool assists with default data of eco-profiles of typical energy sources and weighting factors for different assessment methods. This means that the user does not need to supply input, but can choose from a number of default energy sources and assessment methods. As an option, normalized emission profiles can be added for user-defined sources, since such data may be available from local energy suppliers or from public information services. The Eco-factor tool also includes calculation of a so-called "Improvement Potential", which highlights the specific parts of the design that are not performing well or where you can achieve more "points" to improve the overall score.

As an example of the use of the Eco-factor method in the design process we consider the pre-design of an office situated in Gothenburg, Sweden. The particular alternative that is shown as an example is that the building team is considering optimising the size of cooling equipment in order to improve the efficiency. The maximum permissible indoor temperature during working hours determines the cooling load. In a design for a standard office, the maximum permissible indoor temperature is 23 °C. The question is whether the building will have a better performance if this temperature limit is increased by 2 °C. Acceptance of a higher maximum indoor temperature level will reduce the cooling load but may have adverse effects on the indoor climate. The Eco-factor tool is applied in order to assess the design.

Figure 4 shows the input data in the tool for the case with a maximum indoor temperature of 23°C. The Gothenburg district heating system is used as the heating energy source, and production data is supplied by Gothenburg Energy, which is converted to emissions with an Internet tool (Wahlström, 2003; EFFem, 2005). EU average electricity is used as the cooling energy source. The energy uses are taken from the parameter study (Brohus et al., 2004) and the EPS environmental assessment method is used. A clothing insulation of 1 clo is chosen, which is representative of most of the Swedish year. The results are illustrated in Figures 5 and 6.

To allow a maximum indoor temperature of 25 °C instead of 23 °C is above the limit of acceptable indoor temperature, and this is reflected in a large negative effect on the Indoor Climate Eco-factor. At the same time we can see that the improvement in the Energy Eco-factor from reduction of the cooling load is very small. We can conclude that it is not beneficial to increase the indoor temperature above 23°C.

One option could be to use the high maximum temperature in the summer when the outdoor temperature is also high, which will give a clothing of 0.5 clo and no change in Indoor Climate Eco-factor between 23 °C and 25 °C. However, the cooling equipment needs to be designed for the winter case anyway.

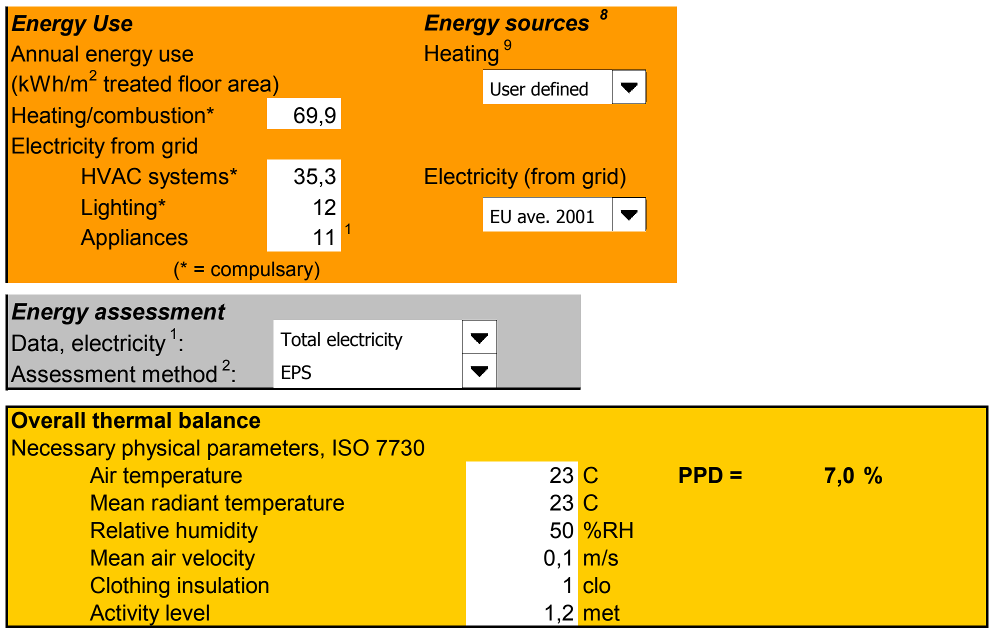

FIG. 4: Input data in the Eco-factor tool for the first case with maximum indoor temperature of 23 °C.

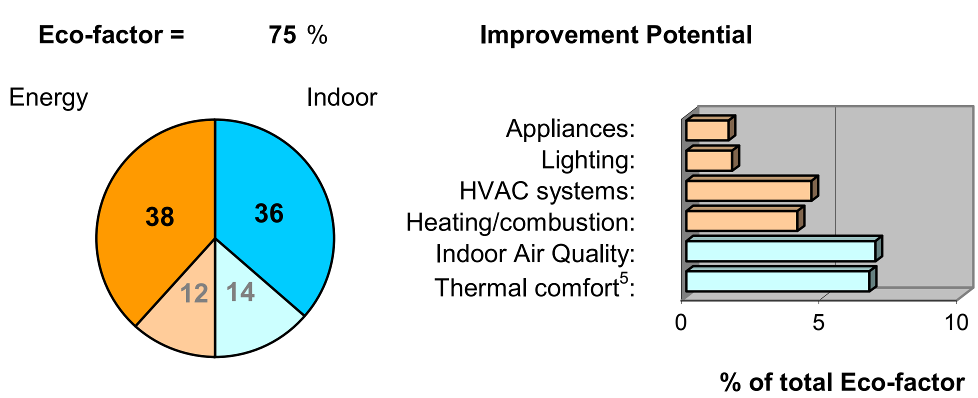

FIG. 5: Eco-factor tool result for the case with maximum indoor temperature of 23 °C.

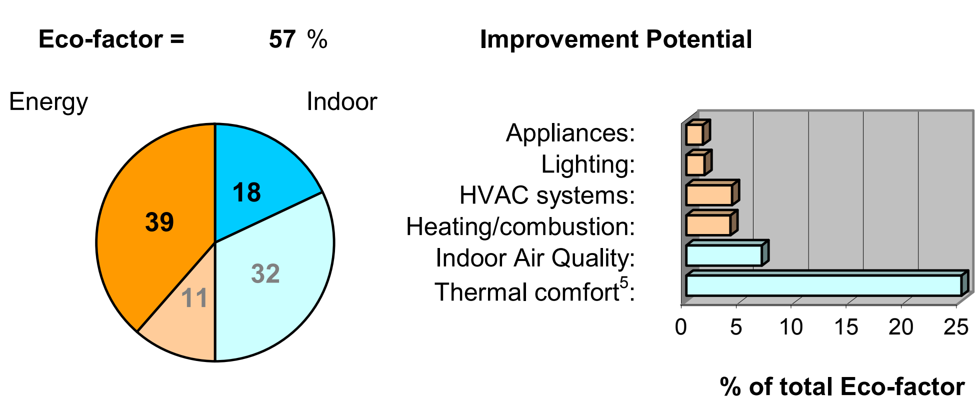

FIG. 6: Eco-factor tool result for the case with maximum indoor temperature of 25 °C.

4. Discussion and conclusion

An Eco-factor method has been developed that aims to assist architects, engineers, builder and clients in the decision process of office building design. The Eco-factor method has been devised to enable assessment of the energy-related environmental impact and indoor climate, and to facilitate the calculations the method has been programmed into an Excel-spreadsheet tool together with a small database. We find that the method has several benefits:

- 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 operation, e.g. by decisions made by the control system of the building, since indicators are measurable.

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.

5. Acknowledgment

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

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