A design oriented indexing system for energy use and indoor climate

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ABSTRACT
An assessment concept is being developed for iterative design of office buildings with integrated energy and indoor comfort solutions. 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 to 100%, called the 'Eco-factor'. Only the operative phase of the building life cycle is considered. Only indoor climate aspects that are closely inter-related with energy use are considered: Thermal comfort and Indoor Air Quality. The 'Eco-factor' is calculated by scoring functions based on physical properties. This paper describes how indoor climate is incorporated in the Eco-factor method.

INDEX TERMS
Design; Comfort; Energy; Environment; Integration

INTRODUCTION
Problems in office buildings are often related to the design and control of the indoor environment and of the building as an energy system. The often interconnected nature of the above two issues is important to take into account, since for instance internal and external heat loads, temperatures and air change rates, affect both energy use and indoor comfort. Thus, to avoid the indoor climate problems that are seen all too often in contemporary office buildings, it is essential that energy optimization is integrated with assessment of indoor climate. Improvement on one issue is only wanted if it does not have detrimental effects on the other. Examples:

- Large glazed facades facing south to improve passive solar energy, may lead to overheating problems in summer, which again may lead to electricity use due to extra cooling demand.
- Natural ventilation used to decrease electricity use, may lead to inadequate indoor air quality when the differences between indoor and outdoor pressures are too small to give sufficient driving forces.

An assessment concept is being developed that can be useful for assisting building designers in creating solutions to these problems. The assessment is meant 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 supplied a quick overview of the effect of changing key parameters as room height, air change rate, internal loads, control strategies, etc., in rapid iterations, showing potential for improvements on either energy related emissions or indoor climate, but at the same time highlighting perhaps unforeseen dangers of compromising indoor climate in order to improve the energy performance, or vice versa.

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METHODS

An evaluation method has been devised that incorporates environmental effects of energy use with thermal and atmospheric indoor climate in an index or 'score' on a common scale from 0 to 100%, called the 'Eco-factor'.

The Eco-factor is based on a hierarchical system, where scores on upper levels is composed by weighted addition of sub-scores from lower levels, which in turn are calculated by scoring functions based on indicators of physical properties (lowest level). For the indoor climate part these indicators include namely indoor temperature, velocity, and concentration fields. The energy part considers energy use distributed on energy sources, and the resulting air-borne emissions. This paper describes how indoor climate is incorporated in the Eco-factor method. The energy part is described in (Bjørn *et al.*, 2003).

The Eco-factor has been developed mainly with design in mind, even if we intend that it can be used also for environmental optimization of choices made by control systems. The building designers have different needs at different stages of the design process. Often, for a first assessment, one is satisfied with viewing overall scores that are synthesized from a number of inputs. Later, more detailed information about individual categories can help to make clear cause-effect relationships, and to show possibilities for improvement.

Scope

Only major indoor climate aspects that are closely interrelated with energy use are considered:

- Thermal comfort => temperature range => heating, cooling
- Indoor Air Quality => ventilation => electricity

We have not included lighting in the indoor climate part of the Eco-factor, but only in the energy part. 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.

Only the operative phase of the building life cycle is considered, since studies show that—with present building and energy practice, which is to a large extent based on combustion of fossil fuels—the operative phase accounts for the large majority of the energy related emission to the external environment, see Cole and Kernan (1996). Of course, indoor climate is by its very nature only related to the operative phase.

Performance Assessment

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. We use quantitative, results oriented indicators that can be calculated directly on the basis of physical parameters in the design phase (or measured in the operative phase).

To define a scale for each indicator, we need at least two fixed points as benchmarks. These could typically be chosen as an 'average' level, and an 'upper' level, represented by either data from existing buildings ('best practice'), or from theoretical considerations ('best possible'). It is also possible to include more than two benchmarks, for instance both 'best practice' and 'best possible'. Less than average or even negative benchmarks can be defined. This has been the case with the scoring functions in GBTool (Cole *et al.*, 1999) and in ESCALE (Gérard *et al.*, 2000). However, we have chosen to keep a fixed scale from 0 to 100% with linear score functions, since this is easy to understand intuitively.

RESULTS

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), using PPD (Predicted Percentage Dissatisfied) as indicator for overall thermal balance, and PD (Percentage Dissatisfied) for local thermal discomfort—except for draught, which uses ‘Draught rating’ (DR).

For calculation of overall thermal balance, environmental parameters include operative temperature (weighted sum of air and mean radiant temperatures), mean air velocity and relative humidity. Human factors include activity and clothing.

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, vertical air temperature difference, radiant temperature asymmetry, and warm or cold floors.

Atmospheric Comfort

The best way to achieve this 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(s).

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.
- Airflow rate—larger ‘dilution’ means lower concentration and better Indoor air quality (IAQ). Note that larger airflow rate also often means larger energy consumption.
- Ventilation type and effectiveness.
- Activity of persons.

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:

- PD due to dissatisfaction with the ‘smell’ of the air, with body odour from a person (measured in olf) being the reference standard, but also building materials, ventilation ducts, etc., can 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 input for control systems. However, if substantial pollutants (apart from people) are involved, this indicator will not be adequate. Dissatisfaction (PD) may be found using the guidelines in (EN CR 1752, 1992).

Score Functions

EN CR 1752 operates with three pre-defined levels of expectation: (A) High, (B) Medium and (C) Moderate level of expectation. We have used category B as ‘average’ (50%) benchmark in the following score functions. We have also used a ‘best possible’ benchmark, derived from the ISO 7730 standard.

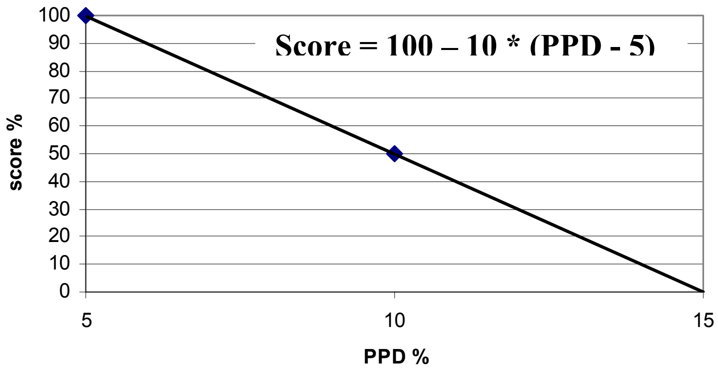

Figure 1 Score function for overall thermal state of the whole body with indicator PPD. The upper benchmark is chosen as 5% PD, since it is practically impossible to achieve better results, due to variation of thermal preferences in population.

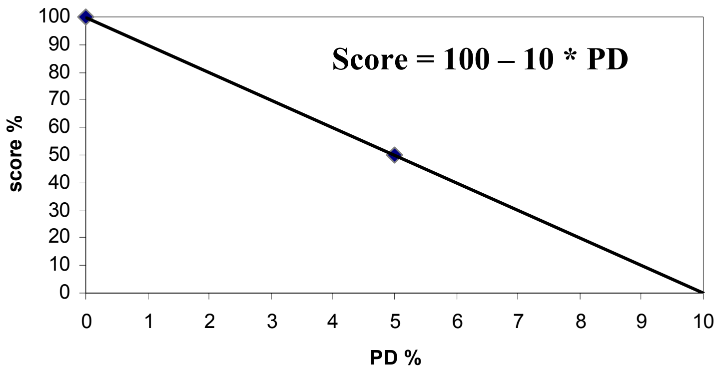

Figure 2 Score function for local thermal discomfort due to radiant temperature asymmetry. Upper benchmark: If no asymmetry exists, there is no thermal stress.

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.

In a similar fashion, score functions have been devised for the remaining discomfort indicators.

- Draught rating: Score = 100 – 2.5 · DR
- Vertical air temperature difference: Score = 100 – 10 · PD
- Warm or cold floor: Score = 100 – 12.5 · (PD – 6)
- IAQ: Score = 100 – 3.3 · (PD – 5).

Note: The score in each category is confined to lower and upper boundaries of 0 and 100%, respectively.

Weighting of Impact Categories

We have defined four levels of details for calculating the Indoor climate part of the Eco-factor, as illustrated in Figure 3.

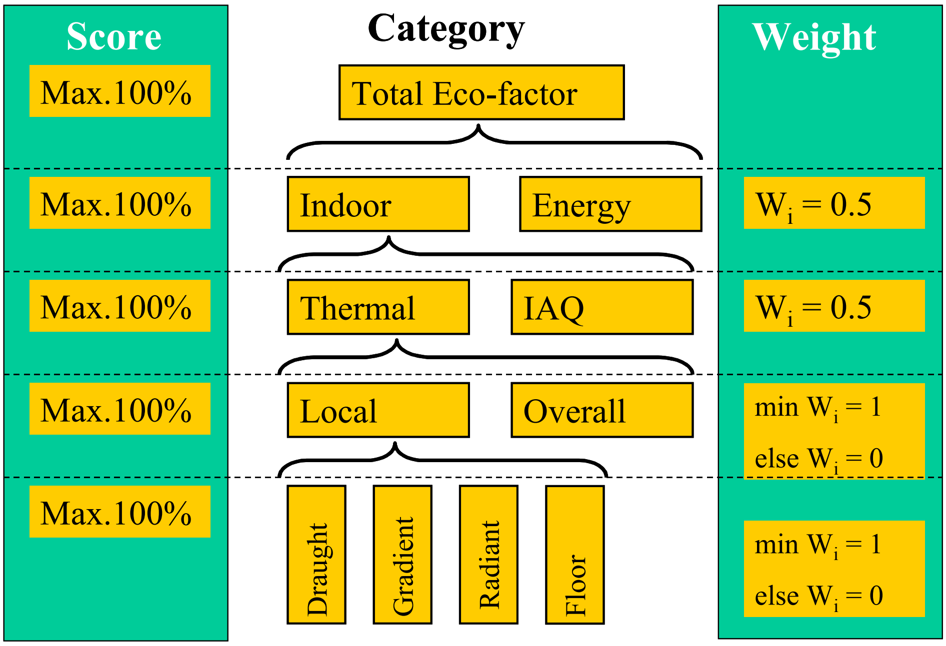

Figure 3: Weight factors used to add subcategories. $W_i = 0.5$ means that each category is weighted by 50%. 'min $W_i = 1$, else $W_i = 0$' means that only the subcategory with minimum score is included while all other categories are disregarded.

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 and for defining one's own weight factors.

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 standard, which demands that all issues are addressed satisfactory. 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 final score on each level is defined by the sub-indicator which achieves the lowest score. This will assist to quickly identify problems, instead of obscuring problems by adding several subcategories to an overall score.

Simplified Example, Thermal Comfort

Assume a hypothetical room with mean radiant temperature $T_{rm} = 20°C$, indoor air temperature $T_i = 21°C$, maximum velocity $U_{max} < 0.15$ m/s, activity level 75 W/m^2, clothing insulation 0.7 clo. With the above input, PPD can be found to be 11.0% for 'overall thermal balance'. Score = 100 – 10 * (PPD – 5) = 40%.

The room contains a large, cold window, temperature of inner surface $T_w = 12°C$. Radiant temperature asymmetry is (20 – 12) = 8°C => PD = 3%. Score = 70%. The final score for thermal comfort = 40% (lowest score, $W_i = 1$).

A better insulating window is found: T_w is raised to17°C, T_i to 23°C and T_{rm} to 22°C. Overall thermal balance: PPD = 5.1%. Score = 90%. Radiant temperature asymmetry: PD = 1%, score = 90%. Final score for thermal comfort = 90%, i.e. much better than before.

If we wish to find the indoor climate Eco-factor, we must also assess IAQ. If the score for IAQ is 70%, the indoor climate Eco-factor is 80% ($W_i = 0.5$ for both categories, see Figure 3).

The same result would be obtained by installing convective heating in front of the window. But this would have a penalty on the energy side of the Eco-factor, unlike improved insulation. The latter choice is the better.

CONCLUSION AND IMPLICATIONS

The Eco-factor method has been devised to enable environmental assessment of different energy sources and techniques in the design (and operation) of energy efficient buildings with low environmental impact and desired indoor comfort. We find that the method has several benefits:

- is common, easily understandable scale for comparing solutions;
- supports an iterative procedure, useful for 'integrated design';
- easy to adopt system in future to take care of more issues, or divide into sub-issues, while keeping the same fixed scale;
- possibility to exclude issues when no information exists;
- not an advantage to focus on single issues, since poorly performing parts of design is penalized, i.e. holistic approaches are preferable to obtain high scores.

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. This is however not an integral part of the Eco-factor itself, which aims only to quantify physical properties of the building related to its operation phase, but is part of the extended assessment and design concept being developed.

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