Key Performance Indicators for the Indoor Environment

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Summary

The overall quality of the indoor environment in which people live, work and spend their time and artefacts remain, is the result from a complex integration of a large number of physical attributes. These attributes result from an integration of a large number of building components. Assessing the individual components and assessing attributes individually is important, but does not guarantee unambiguously a healthy, comfortable and safe indoor environment. Prescriptive solutions may support in arriving at the desired result, however, for innovation the performance based approach should be the point of departure and this starts with performance indicators to assess this performance.

Within the ongoing EU FP7 Coordination Action PERFECTION a set of performance indicators has been developed to assess the overall quality of the indoor environment in buildings. The main focus is on issues such as comfort, health and safety, but also accessibility, positive stimulation of people and, more generally, sustainability have been covered.

This paper describes the constraints that relate to the development of such a framework and the changes proposed resulting from the expert assessment. An example of an indicator description and evaluation procedure is provided. From a long list of indicators identified a first proposal for a list of so-called Key Indoor Performance Indicators (KIPI's) and their evaluation procedure has been derived. This list has been assessed by different experts in different settings through various data collection methods, such as interviews, workshops,and survey. The development work has been carried out through iterations

The long-term aim of the project is to help enabling the application of new building design and technologies that improve the impact of the indoor built environment on the human well-being. The presented KIPI-list is an important starting point for that.

Keywords: Indoor Environment, Performance Indicators, Perfection, Health, Comfort, Safety, Accessibility, Functionality, Positive Stimulation

1. Introduction

The overall quality of the indoor environment in which people live, work and spend their time and artefacts remain, is the result from a complex integration of a large number of physical attributes. These attributes result from an integration of a large number of building components. Assessing the individual components and assessing attributes individually is important, but does not

guarantee unambiguously a healthy, comfortable and safe indoor environment. Prescriptive solutions may support in arriving at the desired result, however, for innovation the performance based approach [1] should be the point of departure and this starts with performance indicators to assess this performance.

One of the objectives of the ongoing EU FP7 Coordination Action PERFECTION is to draw up an inventory of current performance indicators, standards, regulations, guidelines, research activities and policies used in design and construction of the built environment, focusing on the indoor environment [2]. The result of that is a framework of performance indicators that together allow for a concise assessment of the indoor environment in the design and use phase of a building. A framework with so-called Key Indoor Performance Indicators (KIPI's) has been developed [3] (see Figure 1).

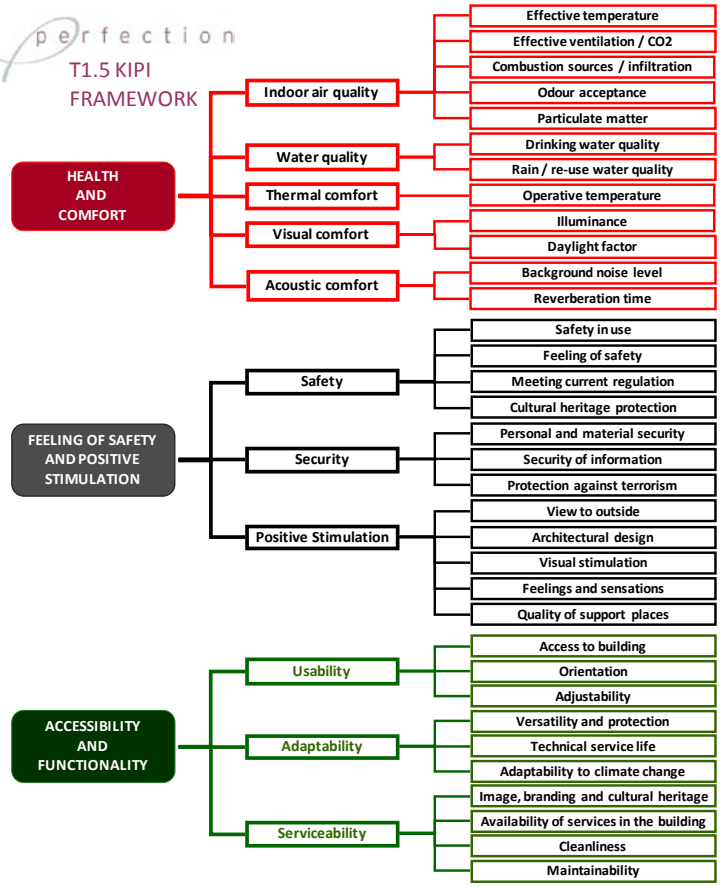

Figure 1. D1.5 initial KIPI Framework [3].

The objectives of the research described in this paper were (a) to provide an updated and optimal version of the framework as shown in *Figure 1* by adding and removing indicators to and from the initial framework; (b) to identify missing indicators; and (c) to develop/improve assessment methods for the performance indicators.

These results follow from the consultation of experts within and outside the core consortium and committee of experts and stakeholders (so-called CES-members). Before providing the detailed methods applied and the obtained result, i.e. the updated version of the framework, the paper will discuss several assumptions and constraints with respect to the performance indicators chosen as part of the KIPI framework and with respect to the assessment procedures developed. This is deemed relevant to position the result developed.

1.1 Point of departure and constraints

Though not explicitly mentioned, the point-of-departure for the assessment of the indoor environment within PERFECTION is to arrive at a healthy indoor environment according to the

definition as provided by the World Health Organization (WHO): "*Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*" [4]. As such the development of the KIPI framework provides a wider range of indicators than if only physiological health would have been included. The main performance category 'Health' as displayed in *Figure 1* relates to the physiological part. Although more focused on social well-being, the other proposed main categories (Comfort, Feeling of safety, Positive stimulation, Accessibility and Functionality) may also include indicators that directly link to the physiological part of the definition of health. The improved framework will follow this point-of-departure as well.

The KIPI Framework as shown in *Figure 1* is the resultant of an optimization that includes earlier work performed (see e.g. [5], [6], [7]). This earlier work consisted of an extensive review and overview of performance indicators covering the mentioned categories. As a result a long listing of more than 100 performance indicators has become available. Though many more indicators may be found in literature, these indicators were assumed to have general applicability with respect to a number of building types (office, school, housing, hospital and exhibition).

Within the PERFECTION project the intention is to arrive at an assessment procedure to qualify the performance of the indoor environment that can be applied in practice. This means that constraints such as time and economy should be taken into account, though they have not been quantified. Therefore, the available long list has been reduced to a selection of 34 so-called Key Indoor Performance Indicators (KIPI's). As such this KIPI-list is a balance between being as complete as possible and arriving at a framework that can be applied in practice. Furthermore, it is important to avoid overlap between categories. With these constraints in mind, and based on the expertise within the consortium and literature review, the KIPI Framework in *Figure 1* has been developed. In a second step, a wider expert consultation was performed. It allowed for assessment of the obtained balance, and corrections where found necessary. In this analysis the option is also open to identify missing indicators, i.e. not on the long list. Furthermore, input is obtained from case studies as performed within the project.

For the selected performance indicators that are part of the KIPI framework short descriptions and assessment procedures have been developed. A uniform indicator template was applied and summarizes the information as shown in *Table 1*. An example is presented in the Annex.

Table 1. Uniform indicator template summarizing information needed in assessment.

Name	**Description**
Framework position	Indicates the main category to which the performance indicator belongs
Indicator name	Performance indicator name
Indicator unit	Qualitative or unit of measurement
Indicator description	Short explanation of the indicator and if required intention of assessing this performance indicator
Applied in building types	Identifies for which building types the performance indicator should be assessed (more than one building type possible) (office, school, housing, hospital, exhibition)
Impacts of indicator	Identifies in which area the indicator has impact [social and cultural/environmental/economical] (more than one impact category possible)
Assessment	Consists of (1) information on the type of assessment (expert review, survey, selection from list, measurement, calculation, simulation) and (2) information on the assessment and related assessment levels [distinction of 5 levels A (best) – E (lowest); D (current national regulation)]. This information is provided for a simple assessment and for a detailed assessment, both in the design phase and the operation phase.
Example	If found sensible, an example is provided to clarify the performance indicator and/or assessment further.
References	Any references mentioned are included. For the main categories Health and Comfort an annex is provided with a more detailed description of the assessment procedures.
Comments	Additional information and/or constraints to the indicator or assessment can be provided.

The selected indicators for the KIPI framework are meant to be used for the general assessment of the performance of the indoor environment of a building. It should be possible to assess the

indicators in the design as well as at the operation phase of the building. Though it was strived for to develop an assessment procedure with a low threshold level, at least for the simple assessment, assessment of the KIPI indicators still requires specific expertise and therefore is meant for building and real estate professionals. Nevertheless, other stakeholder groups, such as end users of indoor spaces are considered as an essential source of information in the assessment.

With respect to the assessment methods defined, the intention has been to provide an assessment method that relates as much as possible directly to the performance indicator. Indirect assessments via prescriptive requirements or assumptions for technological solutions that have been applied in the design/construction are avoided as much as possible. As a result, assessment sometimes is not straightforward and expert review and/or complex measurements or simulations are required to obtain the result. This certainly holds for the detailed assessment procedures.

As the KIPI-list is a balance, care should be taken not to widen assessment procedures for a performance indicator as to implicitly include information on performance indicators that are not on the list and add further weight to an indicator. Within the context of the project, indicator weighting is discussed.

Furthermore, it is important to note that the KIPI-list and assessment of the indicators on the list reflect sustainability in the broad sense of its definition. For example, energy use as such is not regarded as an indicator related to the indoor environment within the context of the KIPI-framework. Of course the design of the indoor environment in the end will find an optimization between performance of the indoor environment and other performance reflecting for example energy and material use.

The number of assessment levels has been limited to five levels (A [best] to E [lowest], with D assuming adherence to current national regulations). This still assumes quite a detailed level of assessment which may not be applicable to every indicator as for example physiological health related indicators. Therefore, in exceptional cases a performance indicator may not be assessed to these five levels. Furthermore, for some indicators different target values may be proposed to differentiate between the levels. Example target values are provided in the project, certainly for the detailed assessment. These values however should be regarded as informative. They should be agreed upon by the client and the design team, and may find national or cultural considerations. The same accounts for qualitative terms that have been applied in the performance level assessment. National and cultural considerations could also be reflected in the weight that is given to the specific indicators in the framework.

Summarizing the above, several constraints are linked to the KIPI-framework as is developed within the PERFECTION project. Within this context, assessment and improvement of the initial version of the KIPI-framework was sought for.

1.2 Methodology

In order to obtain the objectives posed the following methodology was assumed:

1. A survey and discussion with members of the committee of experts and stakeholders of PERFECTION in different settings. A structured questionnaire was used for that.
2. Face-to-face and telephone interviews with experts not involved in the project in order to get feedback about the initial framework. The same structured questionnaire was used to drive these interviews and to collect the opinions.
3. A brainstorming session with experts in Israel.
4. A survey through a wide network of people (to be performed).

The KIPI indicator framework has been developed through multiple steps. First, a committee of experts and stakeholders (indicated as CES members; in total 32 members) reviews and discusses the results obtained. The proposed framework as shown in *Figure 1* was surveyed through a structured questionnaire. The questionnaire requested input on the importance ([5]-high to [1]-very low; [0] not relevant) of the individual indicators selected within the framework. Furthermore, applicability in practice was assessed, as was agreement with national strategies

with respect to the indoor environment. Finally, for each of the three main categories identified the three most and least important indicators were asked for as well as potentially missing indicators. The CES members were provided with all the descriptions of the indicators as summarized in *Table 1* in order to better perceive the indicator names as included in the framework. The survey was carried out in two workshop sessions; Paris in November 2010 and Prague in March 2011.

Then, the interviews with external experts not participating to PERFECTION project were applied. In total 22 experts were surveyed from five different countries. These interviews served as an input for a brainstorming session. The brainstorming session with 20 external experts from relevant areas (e.g. architects and safety experts) took place at Tel Aviv University in October 2010.

Finally, focussing on the assessment descriptions, results from application of the initial framework in 17 case studies (different building types; simple assessment) were used to improve these descriptions.

Based on the input as described above, an improved version of the KIPI-Framework has been proposed. As a last step, an internet survey will be performed to reach a wider audience. This survey will not assess the individual indicators but will ask for the selection of the most important ones, the least important ones and missing indicators. As the project also wants to identify potential and barriers with respect to innovation and development of regulations and standards, this will be part of the survey as well. The results from this survey are not yet available. The improved version of the KIPI-framework that has resulted from the input described and shown in the results section will be the point-of-departure for this survey.

2. Results

Based on the point-of-departure and the results from the survey, interviews, workshop sessions and case studies, an improved framework has been developed, and updated versions of the performance indicator descriptions and assessment procedures have been defined. The improved KIPI-framework is shown in *Figure 2*. An example of a description for a performance indicator and the related assessment procedure is provided in the Annex.

Compared to the original framework as shown in *Figure 1*, the improved version has the following changes:

- Instead of three main categories, four categories have been defined. The main category ‘Health and Comfort’ has been kept. The other main categories have been specified further to reflect the indicators related to each category better.
- In accordance with the change in main categories, the subcategories have been repositioned to reflect identified agreement between subcategories. The subcategories for Health and Comfort have been grouped under the specified name. In order to allow for a visual distinction of the original categories, the detailed view of the framework will remain to include the original distinction with respect to air quality, water quality, etc. (see *Figure 3*)
- At performance indicator level, the number of indicators was reduced from 34 to 31. The performance indicators ‘Odour acceptance’, ‘Rain/re-use water quality’, ‘Architectural design’ and ‘Visual stimulation’ were removed from the list. In the subcategory ‘Positive stimulation’ the performance indicator ‘Privacy’ was added.
- Several performance indicators were renamed or redefined to better reflect the content of the performance indicator and avoid confusion. *Table 2* summarizes the main changes made and gives a short explanation for that.
- Besides the changes in the definition of the indicators, many definitions and assessment procedures for the individual indicators were improved to account for remarks made in the survey, interviews, workshops and case studies.

Figure 2. Improved KIPI-framework.

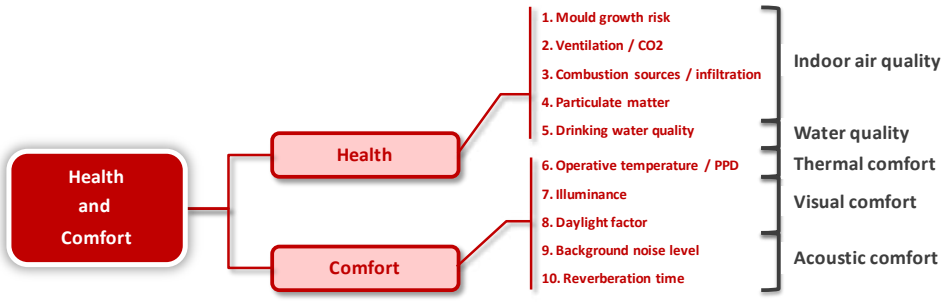

Figure 3. Detail view of the Health and Comfort main category with the original distinction included.

The results obtained from the survey, interviews and workshops did not result in the identification of important missing indicators. Identified missing indicators by the participants in the different consultation settings generally were linked to performance indicators that were already identified in the long list of performance indicators but not found fit to be included in the KIPI list. Other indicators identified as missing were out of the scope of the KIPI framework because, for example, related directly to technological solutions or to energy use.

Table 2. Overview of changed performance indicator names with short explanation.

Original name	Improved name/redefinition	Explanation
Effective temperature	Mould growth risk	Indicator name was not understood, scope of this indicator was reduced.
Effective ventilation/CO_2	Ventilation/ CO_2	The term 'effectiveness' was less well understood and not really assessed
Operative temperature	Operative temperature/PPD	For consistency with the assessment procedure
Cultural heritage protection	Building type specific	Original indicator addressed only the suitability of the indoor environment (indoor conditions) to host artworks and other cultural heritage objects, and thus was aimed for a very restricted group of buildings. The improved version allows assessment of performance for building specific requirements that e.g. in case of hospitals consists of hygiene.
Protection against terrorism	Reliability in exceptional cases	Allows for a broader assessment than terrorism alone (e.g. natural disasters)
Quality of support places	Availability and quality of recreational spaces	The meaning of "support places" was not well understood. Their availability was added because otherwise there is no sense in evaluation of quality either.
Access to the building	Access to and in the building	In some cases this indicator was understood to contain accessibility in a broader sense (outdoors, public transport etc.)
Orientation	Wayfinding	Orientation was understood to include also outdoors of buildings. Wayfinding is used in ASTM standards.
Image, branding and cultural heritage	Branding and cultural heritage	Too many aspects were combined into one indicator. Their interrelation was not well understood.

3. Discussion

The results from the work performed confirmed the difficulty in arriving at a framework with a limited number of indicators for assessing the broad area of indoor environment. As such the improved KIPI-framework can be regarded as a compromise (or better balance) between the limitations set for practical application and limitations set for covering the indoor environment to a sufficient detail.

The input from the CES members and external experts was valuable to indicate the weak points in the initial version of the framework. Several misconceptions about indicator names, such as 'Effective temperature', clearly showed the need for a redefinition. Other indicators, such as 'Odour acceptance', were rated differently by different experts. Argumentation for removing this specific indicator from the list was found in the difficulty of assessing the indicator in the design phase. As such the performance indicator did not agree to the performance based building requirement: assessment in the design and operation phase is required to verify if performance in the design is met in the operation phase. Several indicators were found to have different importance based on national or cultural reference. An example of such an indicator is 'Drinking water quality'. This indicator nevertheless remained in the improved framework to cover the width of the indoor environment assessment. If an indicator is regarded less important, this may be reflected by incorporating a lower weight to such an indicator. Since the importance of the indicators also highly depends on the building type, different weightings for the KIPI framework have been discussed for the five main building types (office, school, housing, hospital and exhibition).

Assessment procedures were updated to correct inconsistencies reported and to include changes proposed to the indicator name. As an example, the original indicator 'Effective temperature' was renamed 'Mould growth risk'. In the assessment of the original indicator also the perceived indoor air quality was reflected. With the change in name the assessment procedure was changed accordingly. A different example is given by the performance indicator 'Particulate matter'. In order to adhere to some of the comments made with respect to odour, the indicator description has been extended to include a simple check on the building materials applied. This is an exception and can

be regarded as a compromise.

Clearly missing indicators within the context of the KIPI framework were not identified or, if mentioned, already available in the long list of indicators. Subcategories such as 'Positive Stimulation' however seem to be open for further development. An identified problem, also from the input received by the experts, is the generally qualitative basis for assessing indicators in this area. The extension of performance of the indoor environment in terms of psychological positive results however indicates the added value that the indoor environment can provide and which has not very often been underlined so much in indicator systems until now.

Interdependencies between individual indicators have been investigated to avoid duplication in weight of design parameters. The interdependency however was found to be limited and if present was minimized in the updated assessment procedures in the best possible way. As an example artificial lighting was presented as a topic that has relevance in different indicators, e.g. 'Illuminance', 'Feeling of safety', 'Wayfinding' and 'Feelings and sensations'. Though artificial lighting indeed is valued in these separate indicators, assessment is based on different parameters and target values. 'Illuminance' reflects the amount of light available to perform, e.g. reading work. Generally this amount of light is not required and designed differently when the lighting is related to 'Wayfinding'. 'Feelings and sensation' may reflect again other parts of the artificial lighting such as colour.

4. Conclusion

An updated and improved version of the KIPI-framework is presented as a result of the work performed within the EU FP7-CA PERFECTION. This improvement includes definitions of the Key Indoor Performance Indicators for indoor environment quality and related assessment procedures.

The KIPI-framework is the result of a balance between being complete and practically applicable. As such no areas were identified for which indicators were (obviously) missing. The KIPI-framework however has the flexibility to incorporate such indicators if found and deemed important.

Later in the project the here shown improved KIPI-framework will form the reference for the development of an internet-based tool aimed for product developers and end-users (www.indoorperformance.net). It will remain in use after the project's lifetime and will hopefully guarantee the continuous use of the assessment methodology developed in this project.

5. Acknowledgements

The study presented in this paper is part of the European research project on Performance Indicators for Health, Comfort and Safety of the Indoor Environment (PERFECTION, www.ca-perfection.eu, FP7 Grant Number 212998). All CES members, experts and PERFECTION partners that participated in the study are gratefully acknowledged for their contributions.

6. References

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7. Annex

Example of a performance indicator description and assessment procedure.

1. Framework position:

Security

2. Indicator name:

Personal and material security

3. Indicator unit:

Qualitative

4. Indicator description:

This indicator checks if adequate protection measures are taken against criminality.

5. Applied in building types: (select)	6. Impacts of indicator: (select)
■ Offices	■ Social and cultural impacts
■ Schools	■ Environmental impacts
■ Housing	■ Economic impacts
■ Hospitals	
■ Exhibition	
■ Other	

7a. Simple assessment in design:	8a. Simple assessment in operation:
■ Expert review (subjective specialist judgement)	■ Expert review (subjective specialist judgement)
□ Survey (asked from e.g. user such as POE)	□ Survey (asked from e.g. user such as POE)
□ Select from the list	□ Select from the list

Assessment description in design:	Assessment description in operation:
A: Entrance doors and windows are burglar-proof. There are an alarm and a monitoring system linked to a police office or security firm. B: Entrance doors and windows are burglar-proof. Presence of an alarm system. C: Entrance doors and windows are burglar-proof. D: Entrance doors are burglar-proof. E: Nothing done for security. Not selected.	A: Entrance doors and windows are burglar-proof. There are an alarm and a monitoring system linked to a police office or security firm. B: Entrance doors and windows are burglar-proof. Presence of an alarm system. C: Entrance doors and windows are burglar-proof. D: Entrance doors are burglar-proof. E: Nothing done for security. Not selected.

7b. Detailed assessment in design:	8b. Detailed assessment in operation:
■ Measurement (quantitative value)	■ Measurement (quantitative value)
□ Calculated or simulated value	□ Calculated or simulated value
□ Select from the list	□ Select from the list

Assessment description in design:	Assessment description in operation:
A: Risk analysis has been realised and the security measures taken are higher than what is required by the risk analysis. B: Risk analysis has been realised and the security measures taken are adequate for the estimated risk. C: Risk analysis has been realised and some security measures are taken. D: Some security measures taken. E: No security risk report or measures taken. Not selected.	A: Risk analysis has been realised and the security measures taken are higher than what is required by the risk analysis. B: Risk analysis has been realised and the security measures taken are adequate for the estimated risk. C: Risk analysis has been realised and some security measures are taken. D: Some security measures taken. E: No security risk report or measures taken. Not selected.

9. Example:

10. References:

CEN TS 14383-3: Prevention of crime - Urban planning and building design - Part 3 : Dwellings.
CEN TS 14383-4: Prevention of crime - Urban planning and building design - Part 4 : Shops and offices

Comments:

Concerning the simple assessment method, in a quick evaluation the expert only has to check if measures and/or risk analysis has been done, in accord with what is described in the A to E levels.
In the detailed thorough assessment for dwellings, offices and shops, the assessment should be done following the CEN TS 14383: Prevention of crime - Urban planning and building design - part 3 and part 4. For the other kind of buildings, this has to be realised by an expert (risk analysis and measures to take).