SUSTAINABILITY INDICATORS FOR THE PRELIMINARY ENERGY DESIGN OF OFFICE BUILDINGS

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Summary

The building sector currently represents 40% of energy consumption worldwide. This, combined with the characteristic long service lifespan of buildings, means that building design decisions have long lasting and multidimensional impacts on both society and the natural environment. As a result, there has been a growing interest in the assessment of buildings through the concept of sustainability, considering its three fundamental pillars: economic, environmental and social aspects. However, evaluation schemes are generally developed in the context of building declaration or certification, while few are aimed at providing decision-support during the preliminary design stages. It is during these early stages that key decisions such as overall construction principles and operation strategies are defined, generally with a limited degree of information available. In order to support decision-making during preliminary design, a set of indicators is proposed aimed at evaluating early design alternatives based on a whole life-cycle approach and according to the 3 fundamental pillars of sustainability. Indicator selection is based on database availability for calculation parameters, as well as evolution of information available and the specificity of design decisions at each design stage. Conclusions from this study are focused on the energy design of tertiary buildings, offices in particular, in the French context. The present work is divided into 2 sections: first, a state of the art study of sustainability indicators in buildings is presented; afterwards, the selected set of indicators is proposed and discussed. Conclusions and future work perspectives are also discussed.

Keywords: Decision-support, tertiary buildings, sustainability assessment, preliminary design, life-cycle analysis

1 Context and objectives

The building sector is characterized by high energy consumption rates and high emissions of greenhouse gases. According to figures from the World Business Council for Sustainable Development, the sector accounts for over 40% of primary energy

consumption worldwide, surpassing the impact related to transportation as a whole [1]. This, combined with the characteristic long service lifespan of buildings, means that decisions made during their design process have long-lasting and multidimensional impacts on society and the natural environment.

In recent years there has been a growing interest in studying the multidimensional nature of the impacts related to buildings through the concept of sustainability, considering its three fundamental pillars or dimensions: economic, ecological and social aspects. This is the case of modern certification schemes, which allow for the analysis of a building design through a holistic and integrated perspective. However, these evaluation methods have been developed in the context of environmental or energy declarations, which are done when buildings are already in the final stages of design or during their exploitation phase. On the other hand, it is in the early stages of the design process when there is a greater opportunity to influence the energy performance of a building, through key decisions such as overall construction principles and operation strategies [2]. Only a small number of the assessment methodologies currently available are aimed at aiding decision-making in these preliminary design stages, and in some cases these are limited to one or two dimensions of the concept of sustainability.

In this context, the present work proposes a set of indicators for the evaluation of building design alternatives in the preliminary design stages, based on a whole life-cycle approach and according to the 3 dimensions of sustainability. This represents the first stage in the development of a decision-support tool for the energy design of buildings, i.e. the selection and sizing of architectural elements and technical systems having a direct influence on the energy performance of a building. Conclusions from this study are focused on the energy design of tertiary buildings, offices in particular, in the French context. The present work is divided into 2 sections: first, a state of the art study of sustainability indicators in buildings is presented; afterwards, the selected set of indicators is presented and discussed. Conclusions and future work perspectives are also discussed.

2 State of the art of sustainability indicators in buildings

Besides energy and environmental certification schemes, which aim at validating the final building design and as such are not suitable for directly guiding decision-making in the early design stages, other assessment approaches are proposed in the literature. These include international collaborative projects and other research approaches, which seem more adapted for their use in preliminary building design, and have been used as a starting point for the selection of sustainability indicators in this work.

Of notable mention are the European Commission projects SuPerBuildings [3] and Perfection [4], both led by various European energy agencies. The main objective of both projects is the identification of sustainability indicators in buildings and the standardization of their definitions and calculation methods. The conclusions from these works are proposed as a starting point for new methodologies in the benchmarking and certification of buildings. These two European initiatives greatly complement each other: while the project SuPerBuildings explores the three dimensions of sustainability, therefore providing a comprehensive base of sustainable indicators, the Perfection project focuses solely on the social category, allowing for a much deeper dissection of this often ignored pillar. Another remarkable initiative is the SBA Framework for Common Metrics, currently under development by the Sustainable Building Alliance (SBA) [5]. This project aims to identify

common indicators which may be used at an international level for the assessment, classification and comparison of the sustainability performance of buildings. By proposing a concise number of indicators and focusing on the ecological and social dimensions, this project presents a simple but practical framework for the sustainability assessment of buildings. Finally, the Technical Committee TC350 of the European Committee for Standardization has been established for the development of a suite of European Standards covering the assessment of sustainability for construction products, buildings and the built environment in general. Of particular importance are the European standard EN 15804 [6] and the set of standards EN 15643 [7], which represent the basis of a series of Europe-wide reference documents for the evaluation of the contribution of construction products and buildings to sustainable development, respectively. These standards consider all three sustainability dimensions and are expected to be subsequently adopted in each country in the form of national policies and assessment tools.

As a general rule, the aim of these initiatives is the proposal of appropriate indicators for quantifying the building performance, as well as the homologation of related vocabulary and definitions. These assessment methods agree that when applying the concept of sustainability to buildings, each of the three fundamental dimensions is related to an aspect of performance: the economic dimension is characterized by the financial cost, the ecological dimension through the degradation of the natural environment, and the social dimension by the occupants' wellbeing and their interaction with the building. Various sub-categories compose this last dimension, including safety and security, adaptability, accessibility as well as health and comfort of occupants.

Other research initiatives, such as multi-criteria analysis approaches, are available in the literature but not treated in detail in this study. A number of these initiatives are aimed at aiding decision-support during the energy design of buildings, for instance through the search of pertinent design alternatives through the use of optimization algorithms. It is worth mentioning that these approaches are generally limited to two of the three dimensions of sustainability. This represents an opportunity area for the development of decision-support tools in the domain of building energy design.

3 Selected building sustainability indicators

Based on the previous state of the art study, a set of indicators for the assessment of the sustainability of buildings has been selected, which is presented in Table 1. The selection of these indicators has been based on the consensus between the aforementioned projects and initiatives as well as various operational aspects to be described in each case.

Given that the objective of this study is the selection of indicators related to the energy design of buildings, only the categories directly related to their energy performance have been taken into account. Particularly, in the case of the social dimension, only the category of health and comfort of occupants has been considered, since it appears as the only one which is directly related to the decisions associated with the energy design of a building. For this sustainability dimension, each of the selected sub-categories and their indicators characterize at least an element which influences the building's energy performance: for instance the daylight factor is mainly given by the window type and sizing, the air change rate by the operation settings of the ventilation system, and the airborne exterior sound insulation by the envelope composition. These three elements

affect significantly the heating and cooling demands, which in turn are linked with the hygrothermal comfort.

Regarding the economic dimension, the financial indicator life-cycle cost has been selected to characterize the performance of buildings from an economic perspective, as proposed by the EN 15643 standards and the project SuPerBuildings. This indicator represents the sum of all costs associated with the building during its entire life cycle, considering a discount rate for deferred costs over time. The use of the life-cycle cost allows for an objective comparison between design alternatives with different cost structures. This is a common situation when comparing traditional energy solutions, associated with modest initial investments but considerable operating costs, against highly sustainable or bioclimatic energy solutions, characterized by significant initial investments but low operating costs. Additionally, this indicator may be expressed separately in investment costs and operating costs, allowing for an explicit dissection of the cost distribution of a given energy design alternative.

Tab. 1 *Selected building sustainability indicators*

Dimension	**Sub-category**	**Indicator**	**Units**
Economic	Financial cost	Life-cycle cost	€
Ecological	Physical resource use	Total primary energy use	kWh
		Non-renewable primary energy use	kWh
		Renewable primary energy use	kWh
		Fresh water consumption	m^3
	Waste generation	Hazardous solid waste	Tons
		Non-hazardous solid waste	Tons
		Radioactive solid waste	Tons
	Environmental impacts	Global warming potential	kg CO_2-eq.
		Acidification potential of land and water	kg SO_2-eq.
		Formation potential of tropospheric ozone	kg C_2H_4-eq.
		Depletion potential of the stratospheric ozone layer	kg CFC 11-eq.
Social	Hygrothermal comfort	Percentage of occupation time outside of a comfort interval	%
	Visual comfort	Daylight factor	%
	Acoustic comfort	Airborne exterior sound insulation	dB
	Indoor air quality	Air change rate	m^3

In order to characterize the environmental performance of a building, a number of indicators have been chosen based on the work of the Technical Committee TC350. As it has been previously mentioned, the work of this committee has laid the foundation for the definition of the format and structure of environmental declaration profiles of both construction products and buildings, which are used extensively in the preparation of life-cycle assessments in this industry. In France, the INIES database [8] currently provides free and public access to a catalogue of environmental profiles for construction products based on the format defined by the French standard NF P 01-010, also developed by this technical committee [9]. The introduction of the recently published EN 15804 standard announces a change in the format of these profiles starting from January 2014 [10]. In this work, the environmental indicators that are common to both standards have been selected, therefore ensuring the availability of data for the building evaluation during and after this

transition period. The chosen indicators encompass three sub-categories: physical resource use, waste generation and environmental impacts. These indicators mostly coincide with those proposed by the projects SuPerBuildings and SBA Framework for Common Metrics, mainly differing in a more detailed breakdown of primary energy consumption and waste generation, and the addition of three mid-point impact indicators in the sub-category of impacts on the environment. On a related note, it is worth mentioning that in addition to construction products, the other major contributor to the ecological performance of a building is the energy consumption during its operation phase. The environmental declaration profiles of the typical energy sources used in buildings such as electricity and natural gas, which are required for the evaluation of the environmental impacts associated to this energy consumption, are currently available in France under the format defined by the NF P 01-010 standard. This format is expected to be updated according to the new standard simultaneously as for the construction products [11].

For the indicators of both the ecological and economic dimensions, a whole life-cycle perspective of the building has been considered, which takes into account the environmental impacts and financial costs associated with the building and its components during all building phases, including construction, use/operation and end of life, as proposed by the TC350 standards and the European project SuPerBuildings.

As it has been previously mentioned, the social dimension has been characterized through the category of health and comfort of occupants, as proposed by the projects SuPerBuildings and SBA Framework for Common Metrics. This category is divided into four sub-categories: hygrothermal comfort, visual comfort, acoustic comfort and indoor air quality. On one hand, the hygrothermal comfort represents the satisfaction of appropriate conditions of indoor environment factors such as air temperature, relative humidity and air velocity within a building space. The number of factors to consider may vary depending on the chosen comfort model, therefore a general indicator that takes into account this consideration has been chosen: the percentage of occupation time outside of a given range of hygrothermal comfort conditions. Furthermore, the daylight factor has been selected as the indicator for the visual comfort. This measure represents on one hand the potential use of natural light, which is linked to an increased sense of well-being in occupants, and on the other hand the minimization of artificial lighting needs, which is linked to a reduction in electricity consumption. Both these topics are particularly relevant in office buildings, since the well-being of employees has been directly linked to higher work productivity [3] and artificial lighting represents one of the main contributors of electricity consumption in offices [12]. As for the acoustic comfort, an indicator that characterizes the ability of the envelope of a building to properly isolate it from external noise sources has been selected: the level of airborne exterior sound insulation. The building envelope is a key element from an energy design perspective, since its composition is directly linked to the thermal behavior of the building, so a good compatibility between thermal and acoustic insulation design decisions is necessary. Finally, the air change rate has been selected to characterize the indoor air quality of a building. This value represents the amount of fresh air that is introduced into a building space for the removal of indoor air pollutants. These pollutants include biological emissions, such as carbon dioxide, or chemicals released by construction products, such as formaldehyde. Other possible indicators for this sub-category are the concentrations of these pollutants in the indoor environment, as proposed by the European projects SuPerBuildings and Perfection. However, there is currently no scientific consensus on a methodology to properly estimate these values during the preliminary

stages of design [3], and so an operational-type indicator has been chosen for this sub-category.

4 Discussion

The set of indicators selected in this work represent a comprehensive foundation for the evaluation of energy design alternatives through the concept of sustainability. This evaluation has been based on the characterization of the energy-related building performance through the use of objective and quantitative indicators. This approach is employed in the latest works in the domain of building sustainability assessment, as seen in the state of the art study and other sources, such as the recent French initiative HQE Performance [13]. This is in contrast to other approaches which, instead of quantitative performance indicators, often rely on the mere implementation of a certain number of measures or means of action as a way to validate an energy design, for instance by encouraging the use of certain technologies or materials which are considered to be highly sustainable. This is the case of various green building certification schemes such as the French HQE [14], which may seem to be either complemented in the future by the previously mentioned HQE Performance initiative.

It is worth mentioning that the evaluation of these sustainability indicators is to be adapted to the evolution of information available and the specificity of design decisions at each design stage. This is mainly envisaged to be done through the adaptation of calculation hypotheses and the identification of typologies of solutions, in order to simplify the description of a design alternative at these early stages of building design when specific details of applicable energy solutions are not known.

In general terms, two categories of indicators can be identified based on their mode of evaluation or calculation. On one hand, the indicators representing the economic and ecological dimensions follow an evaluation scheme which is characteristic of the life-cycle analysis methodology. The calculation of these indicators is done by adding together the individual contributions of each element involved during any stage of the life cycle of the building. On the other hand, the indicators associated with the social dimension characterize the performance of a design alternative as a whole, which is given by the resulting interaction between its components. For example, consider the comparison of two design alternatives where the only difference is the addition of an interior wall. From the points of view of the economic and ecological dimensions, the divergence in evaluation results between these two design alternatives would be solely given by a supplementary environmental impact as well as an additional financial cost, which would represent the individual contribution of this element. The evaluation result would not vary if the location or orientation of said interior wall is changed. On the other hand, from a social perspective, especially when considering indicators related to health and comfort of the occupants, the addition of this construction element may cause a change in the dynamics of the building space concerned, possibly resulting in a considerably different evaluation outcome: natural lighting distribution may be drastically affected by shading or reflection produced by the wall, the thermal mass contained in the wall may modify the time-dependent thermal behavior of the affected space, etc. In this case, the evaluation result could certainly vary if the location or orientation of said interior wall is changed.

An implication of this classification is a divergence in the level at which these indicators are evaluated, in terms of the definition of the boundaries of the system under

study. On one hand, in the case of the economic and ecological indicators, the system boundaries may be freely adapted to the goal and scope of the assessment, which may go from a single element up to the entire building. On the other hand, the indicators associated with the social dimension are primarily evaluated at the scale of a building space or area whose comfort characteristics can be considered as homogeneous. Since the final aim of this work is the assessment of the sustainability performance of an energy design alternative of a building as a whole, then these indicators would have to be translated from the scale of a single space to that of the building. In order to do so, the aggregation of these individual results into a single score appears as necessary, which may be done through the use of a weighting function based on the relative importance of these spaces. This discussion is to be further developed in future stages of this work.

5 Conclusions and future work

In this work, a set of indicators for assessing the sustainability of buildings has been presented, which represents the first step in the development of a decision-support tool for the early stages of the energy design process of office buildings. These indicators have been selected from the current state of the art, composed of various international collaborative projects and other research approaches, and are based on a whole life-cycle perspective and according to the three fundamental dimensions of the concept of sustainability. One of the main motivations of this present work is based on the identification of an opportunity area in the development of decision-support tools in the domain of building energy design which are based on the three dimensions composing the concept of sustainability, as it has been briefly mentioned in the state of the art study.

Following the identification of these sustainability indicators, future activities in this ongoing work will focus on developing other aspects of the construction of the projected assessment methodology, which is to be aimed at aiding decision-making during preliminary energy design. The following step is given by the identification of evaluation methods for estimating these indicators, which are to be adapted to the limited availability of information in the early phases of building design. Another step is the definition of reference values for the proper interpretation of the evaluation results of these indicators. These reference values would represent, on one hand, the minimum acceptable effort (representative of the common practice) and, on the other hand, a recommended value (representative of highly sustainable projects). Additionally, a third future activity is the determination of weighting coefficients, representing the relative importance of these indicators. This would allow for the construction of a global sustainability index, to be used to simplify the comparison of design alternatives using a single aggregated scale. It is worth mentioning that these weight coefficients would merely represent a point of reference given for generic building design projects, since these weights actually change from one project to another based on the preferences of the stakeholders. The considerations discussed in the previous section regarding indicator assessment as a function of their classification appears as relevant for this future work activity.

References

[1] World Business Council for Sustainable Development. *Energy Efficiency in Buildings: Transforming the market*. August 2009.

[2] International Energy Agency – Task 23: Optimization of solar energy use in Large buildings. *Integrated Design Process: A guideline for Sustainable and Solar-Optimised Building Design*. April 2003.

[3] SuPerBuildings Consortium. *SuPerBuildings: Sustainability and Performance assessment and Benchmarking of Buildings*. WWW: <http://cic.vtt.fi/superbuildings>.

[4] Perfection. *Perfection: Coordination action for Performance Indicators for Health, Comfort and Safety of the Indoor Environment*. WWW: < http://ca-perfection.eu>.

[5] Sustainable Building Alliance. *A Framework for Common Metrics of Buildings 2010*. 2010. WWW: <http://www.sballiance.org>.

[6] Technical Committee CEN/TC 350 – European Committee for Standardization. *EN 15804: Sustainability of construction works – Environmental product declarations: Core rules for the product category of construction products*. August 2012.

[7] Technical Committee CEN/TC 350 – European Committee for Standardization. *EN 15643-1 – EN 15643-4: Sustainability of construction works – Sustainability assessment of buildings*. 2010-2012.

[8] French environmental product declaration database INIES. WWW: <http://www.inies.fr>.

[9] Technical Committee CEN/TC 350 – European Committee for Standardization. *NF P 01-010: Environmental quality of construction products – Environmental and health declaration of construction products*. December 2004.

[10] INIES technical committee. *Compte rendu du comité technique INIES N°33*. February 8th 2012.

[11] Life-cycle assessment online tool ELODIE. WWW: <http://www.elodie-cstb.fr>.

[12] Observatoire BBC. *Indicateurs issus de l'observatoire BBC réalisés sur 104 projets (Annual report 2010)*. November 25th 2010.

[13] Association pour la haute qualité environnementale. *HQE Performance : Annexe Technique – Bâtiments neufs*. December 22nd 2010.

[14] Certivéa. *Référentiel pour la qualité environnementale des bâtiments : Bâtiments tertiaires – Septembre 2011*. January 20th 2012.