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PROPOSAL OF A PRODUCT INDICATOR AS A TOOL FOR A COMPREHENSIVE ASSESSMENT OF WINDOWS

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Abstract

Windows are elements of great incidence on building consumption and therefore with great saving potential. When designing high-energy efficiency windows, it is possible to negatively influence the indoor environment quality. To ensure indoor environmental quality, hygrothermal comfort, acoustic comfort, luminous comfort, physical-chemical and microbiological contaminants in the air, and the electromagnetic environment must be considered. Of all these aspects, windows intervene in four of them: hygrothermal comfort, luminous comfort, acoustic comfort and air quality. In order to carry out a comprehensive design, designers should study in detail the variables mentioned for each particular case and, consequently, act. This, due to the means and the deadlines with which the prescriber usually counts on, is currently not viable. This research responds to current deficiencies by proposing the development of a product indicator through an integrative procedure for window design that simultaneously contemplates indoor environmental quality, energy efficiency and cost, integrating environmental and socio-economic aspects. The indicator proposed here provides information substantially superior to that currently available to technicians, to be used as a decision making tool.

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INTRODUCTION

Today, climate change is a new challenge which architecture is also facing. In this regard, the EU has proposed an integrated package of measures on climate change and energy, which sets new and ambitious targets for 2020. The Energy Performance of Buildings Directive (EPBD) is the main European standard aimed at ensuring the achievement of the EU's objectives in relation to building construction. Energy Efficiency is one of the greatest energy resources, considering the potential effect over energy dependency from external countries. Within the European Union, four main directives have been developed to set the roadmap for the built environment, towards the objectives to reach by 2050 (European Commission, 2002): Energy Performance in Buildings (EPBD), (European Commission, 2009): Use of renewable energy, (European Commission, 2010): Net-Zero Emission Buildings, and (European Commission, 2012): New directive for Energy Efficiency in Buildings.

The energy consumption of the Construction Sector in Spain represents 30% of the final national consumption of energy (IDAE, 2014). Windows are responsible for between 19 and 32% of air conditioning loads associated with the enclosure (U.S. Department of Energy, 1997). In that sense, windows can be considered as elements of great incidence on consumption and therefore with great potential for associated energy saving. *"The energy saving potential in the CPIV-FIZ studies states that only by upgrading glass U-values from 5,7 and 2,9 to 1,6W/m²K could save 1,115 MGJ (million gigajoules or 26 million Toe (Tonnes of oil equivalent) each year. The CO² reduction was estimated at 82 million tonnes per year"* (Avasoo et al., 2004).

The history of architecture is related to the evolution of the façade, especially the criteria of comfort and hygiene. The need to effectively and rationally provide day-lighting and natural ventilation places the window as a key factor on the psychosomatic wellbeing of occupants of buildings (Boubekri et al., 1991; Leather et al. 1998). When designing high-energy efficiency buildings, it is possible to negatively influence the quality of the interior environment. The health, comfort and productivity of the users of a building are influenced by the interior conditions of this building.

In Spain, in 2010, 10% of households did not have sufficient means to maintain an adequate temperature during the cold months and/or spent a high percentage of their income to cover basic needs (heating, refrigeration, cooking) (Proyecto REPEX, 2012). The European Commission has already included the concept of energy poverty in its energy and consumer protection policies. Directives 2009/72/EC (European Commission, 2009) and 2009/73/EC (European Commission, 2009) of the internal market in electricity and gas oblige Member States to draw up plans to address this issue. Achieving optimum environmental quality will therefore be another objective set by the European Commission, as necessary as achieving an efficient use of energy. The interior environmental quality refers to the state of health and comfort conditions of the different elements that condition our life. The main aspects to be considered to ensure the internal environmental quality must satisfy the conditions of hygrothermal comfort, acoustic comfort, luminous comfort, physical-chemical and microbiological contaminants in the air, and the electromagnetic environment (Bluyssen, 2009). Of all these aspects, windows intervene in four of them: hygrothermal comfort, luminous comfort, acoustic comfort and air quality.

During the 1970s, some publications appeared that referred to a higher incidence of headaches, mucosal irritation and fatigue among workers in large office buildings (Bluyssen, 2009). Subsequently, as early as the 1980s, WHO defines Sick Building Syndrome (SBS) as

a phenomenon affecting building occupants who claim to experience health and comfort effects that appear to be linked to time spent in a building (Gómez et al, 1992). The actual incidence of the problem is unknown, but WHO estimates that it affects 30% of modern buildings and causes discomfort to 10-30 % of occupants (WHO, 1995). Despite the fact that the guidelines for preventing low environmental quality are known and that the negative impacts of these spaces are broadly accepted, the exact relationship between environmental quality and health/well-being has not been fully understood (Bonnefoy, 2007). Thus, indicators related to the quality of life are the most difficult to define, especially those in which the architectural solution adopted has an influence (Boschi, 2002). Bluysen (2010) emphasizes this lack, performs a critical review of the indicators currently applied, and indicates possible ways forward, pointing out that new indicators of comfort and health of buildings are required. To create these new indicators, an approach in which the building and the building components are analyzed as systems in which humans are the centre will be necessary.

The development of IEQ indicators has been approached at building level; different researchers are pursuing various objectives. Che-Ming Chiang and Chi-Ming Lai (2002) have simultaneously addressed aspects of indoor environmental quality and have proposed a global indicator for the analysis of occupant health. Zhe Wang et al. (2015) also conducted a study integrating aspects of environmental quality following a methodology based on subjective surveys and Al Horr Y. et al (2016) performs an exhaustive review concluding which aspects of IEQ have greater influence.

The issues related to sustainable building (AENOR, 2008) refer to the categories: Economic, Environmental and Social (Figure 1). The social category includes the health and wellbeing of the user. This research responds to the current deficiencies by proposing the development of a product indicator as a result of an integrative procedure for window design that simultaneously contemplates indoor environmental quality, energy efficiency and cost, integrating environmental and socio-economic aspects.

Figure1: Aspects of building construction (Source: ISO/TS 21929-1:2006).

A single IEQ value is not proposed but an indicator that simultaneously provides information on the following aspects: daylighting, air renovation, thermal and acoustic insulation, cost and energy efficiency. It will be used as a decision making tool. Previous studies show when designing conventional window solutions, decisions are made to solve partial aspects that influence its overall performance, analyzing the effect of glazing designed to solve thermal aspects on the daylighting spectrum, so important for the regulation of the biological rhythms of users (Arranz et al, 2014). In order to carry out a comprehensive design, designers should study the variables mentioned for each particular case in detail and, consequently, act. This, due to the means and the deadlines with which the prescriber usually counts on, is currently not viable. The indicator proposed below provides information substantially superior to that currently available to the technicians.

MATERIAL AND METHODS

This work is based on two standards. First, the procedure developed in the standard "Indoor Environmental Quality" (AENOR, 2008) is followed, which aims to describe a methodology for the preparation of an initial diagnosis of indoor environmental quality and health. In addition, energy efficiency and cost are incorporated as additional parameters to be considered in the diagnosis. The procedure described in the Standard is applied here to the window product.

Secondly, the Standard "Building construction: Sustainability in building construction-sustainability indicator" (ISO, 2011), which defines the framework for sustainability indicators in buildings is followed to design the proposed indicator here. Indicators are figures or other measures that simplify the available information of a complex phenomenon, such as the environmental impact. As the standard indicates, it is important to confirm who will be the user of the indicator, its need and objective:

- The indicator shown below is primarily intended for window designer, it can also be a useful tool for building owners who decide to replace windows, as well as for manufacturers and other agents in the sector.
- The indicator is considered necessary, since today, the information available on the window is partial, to be able to perform an optimization of this element, a comprehensive assessment tool is not yet available.
- The objective is to help make decisions with as much information as possible, to know how compliance with one requirement can affect others and thus prevent that initially well-meaning strategies result in harmful solutions.

The indicator has been designed as a tool for assessing the suitability of a window in certain orientation, WWR and climatic zone.

Indicator factors

The proposed indicator integrates the assessment of the following aspects: thermal comfort, light comfort, acoustic comfort, air renewal, energy consumption and cost (figure 2).

Figure 2: Aspects that intervene in the Indicator (Source: Authors).

Related to windows, the Spanish Building Code (CTE) defines Thermal Transmittance (U) and Modify Solar Factor (F) in relation to orientation of façade and % window area (CTE-HE, 2013); and Global Sound Reduction Index RA,TR in relation to window/wall ratio (CTE-HR,

2013). The process to obtain the values of the indicator (figure 3) consists firstly in defining specific window products taking into account the factors that the legislation already incorporate: Thermal Transmittance (U), Modify Solar Factor (F), and Acoustic Reduction Index (R), which comply with the regulations for a specific orientation, % window area and climatic zone.

Once the specific windows have been obtained, with different methods and tools values for visible transmittance, air renovation, energy demand and cost factors are calculated.

Figure 3: Scheme of obtaining the different factors (Source: Authors).

Visible transmittance (VT)

In relation to luminous comfort, visible transmittance (VT) is selected because it is a factor that exclusively depends on the components of the window. ISO 15099 provides the method of calculation. To determine the range of values marked in the indicator, calculations are made of the different types of window with the WINDOW program, which provides an analysis method according to ISO 15099. It is a computer program developed by the University of Berkeley for the total calculation of the thermal performance indexes of windows (U-values, solar heat gain coefficients, shading coefficients and visible transmittances). VT is calculated with solar control elements similar to those considered for the calculation of Modified Solar Factor defined in the Spanish Building Code (CTE DB HE).

Air renovation

In this case, a classification of existing air vents in the market according to their performance has been made; a value for each of them has been given in the indicator.

Table 1: Values adopted by the different types of air renovation mechanism in the indicator (Source: Authors).

TYPES OF AIR RENOVATION MECHANISM		
1	Air Vent with thermal bridge	20
2	Air vent with thermal bridge break	30
3	Air vent with thermal bridge break and with self-adjustment function of pressure or humidity	40
4	Air vent with thermal bridge break, with self-adjustment function of pressure or humidity and adjustment by the user	50
5	Air acoustic vent with thermal bridge break, with self-adjustment function of pressure or humidity and adjustment by the user	60
6	Air acoustic vent with thermal bridge break, with self-adjustment function of pressure or humidity and automatic (smart) adjustment	70
7	Air acoustic vent with thermal bridge break, with self-adjustment function of pressure or humidity and automatic (smart) adjustment and air heat exchange	80
8	Air acoustic vent with thermal bridge break, with self-adjustment function of pressure or humidity and automatic (smart) adjustment and air heat recovery	90

The standard air vent, which is currently placed and complies with the requirements of the Spanish Building Code (CTE- HS, 2013) is given the value 20 (minimum) of the indicator.

Energy consumption (kWh/year)

Regarding the energy efficiency of windows, annual energy consumption is selected as the indicator factor. In order to determine the consumption, different types of windows have been simulated in the DesignBuilder program, obtaining the annual consumption associated to them. An adiabatic space of 30m² and 9m² of facade is simulated, in which values of cooling, heating and lighting consumption associated with the different windows are obtained. These calculations are made for the different orientations and the different percentage of window areas. The calculations are made for an office activity; for the environmental control, the heating set-point temperature is set at 22° and the cooling temperature set at 24°.

Cost

For the calculation of this factor, the cost of the product and of the energy associated with the phase of its use is considered, with an estimated useful life of 30 years. The cost of the selected window products is obtained using the database (COAAT, 2012; CAM, 2011) as reference.

For the cost of energy during the useful life of the building, the price of 1kWh is considered; it is a variable price. For each contracted power segment, the consumption of 1kWh would be charged from €0.15 to approximately €0.18 although this rate is expected to rise considerably in the coming years. For this reason, the cost of annual energy consumption has been calculated considering the highest price, i.e. € 0.18/ kWh.

CASE STUDY: TYPE OF BUILDING AND CLIMATE ZONE.

The requirements windows must fulfil, according the building regulations, depend on climate, orientation, and percentage of window area and use of the spaces. For this, the climatic zones and orientations set by the Spanish Building Code (CTE DB HE) are considered. Therefore, the reference indicator should be developed for all climatic zones, all orientations,

all percentage of window area and all different uses of the spaces. In this research, the indicator is developed for three of the existing climatic zones, analysing its utility, its complexity and its feasibility.

Therefore, as a case study, an office space is selected, the indicator is developed for three climatic zones: zone E1 (city: Burgos, highest winter severity); zone D3 (city: Madrid, high winter and high summer severity) and zone B4 (city: Seville, highest summer severity) due to their possible differences and thus apply it to the proposed indicator.

Figure 4: Climatic Zones of Spain --Building Code – (Source: Authors).

As a result of the calculations described, the proposed indicator takes the structure shown (figure 6). This way, it can be seen how benefits in one factor can affect the rest. Each factor is combined with the rest through the following indicator, which allows a more immediate understanding and comparison of the interactions between the different aspects. The variation of the requirements of acoustic, luminous, thermal comfort, air quality, energy efficiency and cost according to the variables contemplated in the Building Code (CTE DB HE) can be observed.

Figure 5: Indicator (Source: Authors).

Weighting

In order to be able to incorporate all the factors to the same scale of measurement, all of them are transferred to a scale from 0 to 100. The general criterion is to value the factors as 20 when they meet the minimum requirements and to value the factors as 90 when they represent the highest performance.

The range of values that defines the maximum and the minimum in each indicator factor depends on the nature of each factor:

Thermal Transmittance U

The value 20 will be the Thermal Transmittance defined in the Building Code (CTE DB HE) for each of the cases. The value 90 will be $U=1\text{kWh/m}^2$. This is a fairly high value for windows. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_U = 20 + (70 / (1 - U_{20})) * (U_{20} - U_X)$$

Modified Solar Factor F

The value 20 will be the Modified Solar Factor defined in the Building Code (CTE DB HE) for each of the cases. The value 90 will be $F = 0.2$. In this case, there are circumstances in which there is no need for a Solar Control Device, in those cases the Modified Solar Factor of the indicator is 0. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_F = 20 + (70 / (0.2 - F_{20})) * (F_{20} - F_X)$$

Global Sound Reduction Index $R_{A,TR}$

Likewise, the value 20 will be the limit value defined in the Building Code (CTE DB HR) for each of the cases. The value 90 will be $R_{A,tr}=49$. This is a fairly high value for windows. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_R = 20 + (70 / (49 - R_{20})) * (R_X - R_{20})$$

Visible Transmittance VT

In this case, there is no standard indicating any minimum factor. Based on previous studies and calculations it can be observed that in normal situations the values fluctuate between 0.6 and 0.7. Below 0.5 windows will only transmit 50% of the light reaching the window. In this factor, the selected solar control device has great influence. When solar protection is required to avoid overheating, it is important to select devices that allow the access of light. Given the importance of daylighting in human rhythm response, the lower limit of this factor is placed at 0.5 and the upper limit at 0.9. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_{VT} = 20 + (70 / (0.9 - 0.2)) * (VT_X - VT_{20})$$

Annual consumption kWh / year

Based on the values obtained from the simulations carried out, the maximum consumption obtained is considered as the minimum value, with a reduction of 20%, referring to the 2020 objectives of the European Union. In this case, there will be a different minimum and a different maximum for each percentage of window area. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_{\text{kWh / year}} = 20 + (70 / (\text{kWh / year}_{90} - \text{kWh / year}_X)) * (\text{kWh / year}_{20} - \text{kWh / year}_X)$$

Cost €

From the results obtained from the cost calculation and the simulations performed, the minimum value is the maximum cost obtained per m² for each window, which is generally the value obtained in windows facing north, and the maximum value the minimum cost obtained, with a reduction of 20%, referring to the 20 20 20 objectives of the European Union. In this case, there will be a different minimum and a different maximum for each percentage of window area. Based on the above, the indicator factor will be calculated according to the following formula:

$$I_{\epsilon} = 20 + (70 / (\epsilon_{90} - \epsilon_{20})) * (\epsilon_{20} - \epsilon_x)$$

RESULTS AND DISCUSSION

Following the calculations described previously, the minimum values that the products must meet to adapt to the minimum requirements have been obtained for the three climatic zones selected, the orientations, and the percentage of window area according to the Building Code (CTE DB HS) and for office buildings. The following table lists these results for Madrid (Climatic zone D3) in the form of the indicator:

Table 2: Indicators for the city of Madrid (Source: Authors).

Figure 6: Indicator (Source: Authors).

It can be observed (figure 6) how requirements that a window product should meet vary for the same city, for office buildings depending on orientation and percentage of window area. The possibilities of application of the indicator are multiple and are directed to different agents in the sector. The main application considers the indicator as a reference element, which establishes minimums according to the different conditions, which could be included as limit elements in the regulations on which to check the suitability of different products. In figure 7, the indicator of a window product is compared with the reference indicator pointing out which aspects should be optimized in the selected window for that specific situation and in which factor the product performs higher than the requirements.

Figure 7: Comparative application of a product with the reference indicator (Source: Authors).

The indicator can be used for comparative purposes between different products to be used in the same situation; in this case, there will be variations in the different factors. As a decision-making tool, depending on the premises of use and the preferences of the customer, priority to one of the factors compared to the others may be given (figure 7). Another possible comparative application is the same product, for a specific situation making a small

modification. Figure 8 on the right shows the influence of the louvre angle on daylight transmittance, solar factor and consumption.

Figure 8: Comparative application of different products for the same conditions (Source: Authors).

CONCLUSIONS

This work is based on two standards. First, Standard UNE 171330 "Environmental quality of interiors", the guidelines for the realization of the diagnostic process marked by this standard have proved suitable for the achievement of the objectives of the indicator proposal.

Secondly, the indicator obtained is developed according to the framework established by ISO / TS 21928-1, "Building construction: Sustainability in building construction-sustainability indicator" (ISO, 2011), which defines the framework for sustainability indicators in buildings. The indicator fulfills the objective set in the standard of being an element that simplifies information of a complex phenomenon, whose main functions are quantification, simplification and communication, and being an objective and relevant element whose results are reproducible.

The methods for assessing their values are adequate and known and the necessary information is available and accessible, however, the calculation process is not agile enough, having to resort to multiple methods and tools.

The indicator has been proved as a tool for quick and easy understanding; its possibilities of application are multiple. Its usefulness and applicability is directed both to the evaluation of a product versus reference values, and to the diagnosis to indicate deficiencies of an existing product and to the comparison with other elements.

A different tool and method has been used to calculate each of the indicator factors. For an optimal application of the indicator, it will be necessary to develop a tool that incorporates all the necessary information and centralizes the calculations of the different parameters.

The indicator is a live tool, which can evolve and with a vocation of continuity. The structure of the indicator allows the incorporation of new factors according to new available methods or

tools, as could be, a parameter that refers to the embedded energy, the maintenance cost or the glare index. The range of values of each parameter can be adapted to new requirements of the regulations and technological advances that will give rise to innovative elements with better performance.

In relation to the analyzed applications, the incorporation in the regulation of the indicator would have very positive consequences regarding interior environmental quality, mainly related to daylighting and ventilation. The consequences of quality daylighting and high air quality space will improve the comfort, health and productivity of the user and depending on the use of the building, may entail high savings in electricity consumption associated with artificial lighting and air renovation.

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