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From indicators to strategies: Key Performance Strategies for sustainable energy use in Portuguese school buildings

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ABSTRACT

The increase of complexity in school buildings to ensure for users comfort and social and functional demands are changing energy consumption patterns. In the Portuguese context, a recent rise in energy consumption, after a major national refurbishment programme, confirms the need to improve energy management in schools in order to reduce their environmental impact. Besides building design and systems, users are also a determining factor impacting energy consumption in buildings. However, behavioural issues are still among the areas least covered by scientific literature.

The present paper analyses the energy consumption patterns of eight Portuguese case-study schools, with a methodological approach that integrates quantitative and qualitative data analysis. The approach made it possible to link the energy consumption patterns of the schools (selected as Key Performance Indicators) with the user behaviour and management strategies. As a result, six Key Performance Strategies (KPS) were identified so as potentially to enhance the energy performance of school buildings through use and management. Some of the identified KPS can be implemented directly through school management policies to reduce energy use and enhance efficiency. Others can be incorporated in future building design strategies. Some have the potential for being hereafter integrated into the simulation models of buildings' energy performance.

1. Introduction

The increase of complexity in school buildings to ensure for users comfort and social and functional demands are changing energy consumption patterns. Electricity demand has a tendency to rise in the nearby future with the more intensive use of IT as pedagogical tools. Also the compliance with legal ventilation rates is a factor potentially augmenting pressure on energy demand in schools. This is a current important research topic, revealing many times poor air quality conditions in the classrooms [1–4]. Evidences of causal relations between poor ventilation rates and students performance have been also presented [5–8]. Results from a benchmark reveal that primary energy consumption in newer Luxembourg schools has increased due to higher electricity consumption [9]. Dobson and Carter [10] also refer to the trend of increasing electricity use in Scottish schools. An assessment of K-12 schools in the U.S. indicates that office equipment and lighting account for 46% of total electricity use in the American schools [11]. In Poland, a significant discrepancy between predicted and metered energy consumption in a recently modernized secondary school was present by Krawczyk [12], with negative impacts for both economical and environmental goals. Several studies detected inefficiencies and room for improvement which would allow effective energy use reduction. Some report specifically on the context of the South of Europe and the Mediterranean [13–17]. Most of these studies focus the building and systems features and propose strategies accordingly.

In Portugal, a School Building Modernization Programme (SMP) was undertaken between 2007 and 2011 and 106 public secondary schools were rehabilitated [18]. The present research puts in evidence a significant rise in energy consumption after the refurbishment (in some cases achieving 200%), highlighting a transversal situation: addressing energy use is crucial in order to reduce schools' environmental impact and operational costs. Almeida and Freitas [19] researched the indoor environmental quality of two non-retrofitted schools and seven modernized schools. Although results showed an improvement in the indoor air quality and thermal comfort of the late cases, the results were significantly different among those seven schools, revealing the potential impact of user behaviour.

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Several studies confirm the relevancy of the impact of user behaviour on energy performance in buildings [20–25]. Understanding the interaction of users/buildings is therefore relevant to promoting better design strategies to enhance buildings' sustainability [17,26]. According to Christina et al. [27], organizational, social and behavioural issues are still among the areas least covered by scientific literature.

Gunay et al. [28] classified the studies of user behaviour into three main categories: observational, modelling and simulation. Although using different methodologies and tools, they have in common the goal to enhance buildings' energy performance by incorporating relevant users' related data. They also have in common the fact of mostly resourcing to quantitative methodologies for data collection and analysis [20–23,8,24,29]. These studies focus on explaining and describing the engineering procedure of user behaviour when interacting with buildings, usually with a quantitative base.

While quantitative analysis relates to the question of how users perform, qualitative analysis relates mainly to why a specific behaviour and action is adopted [25]. Its aim is to explore the triggers that govern user decision-making processes while interacting with buildings, regarding energy and/or environmental issues [30]. In this sense, the two approaches must be regarded as complementary, mutually reinforcing each other.

Examples of integrated quantitative and qualitative approaches regarding energy use in buildings and user behaviour are still scarce. Gram-Hanssen [31] proposes such an approach, not applied to schools but to households. In his studies, the author concluded that finding new ways to compare quantitative and qualitative data is one of the most interesting fields to explore. Lee et al. [32] concluded that effective measured data and case-study analysis of existing buildings can also help in the validation of simulation tools.

User behaviour is often described as the presence of people in a building and their actions to influence the indoor environment [21,32]. But the interaction of users/buildings fulfils several goals, such as functional or social, and user decisions to achieve environmental comfort are not taken in isolation. The focus on achieving comfort and on quantitative analysis methodologies implies limitations to the amount of variables considered to explain user behaviour, their motivations and potential impacts on energy use. Gunay et al. [28] draw attention to subtle but yet potentially impacting factors, that are not considered because they are not easily or directly measurable. These authors called such factors "marginal factors".

Surveys tend to be the most used tool to address user attitudes and behaviour. Two main issues are not usually addressed by this tool: (1) the differentiation between user attitudes and behaviour and (2) response spontaneity. Qualitative research usually considers open or semi-structured methods, such as focus groups, interviews or free walkthrough observational visits, allowing for a higher degree of freedom of response. On the other hand, most qualitative research focuses on determining relevant factors for a pro-environmental attitude or behaviour, but do not link those with the effective energy consumption patterns. Moreover, qualitative studies focusing on user impact on energy mainly target housing [33] and offices [25] as their research field. Another literature review study [34] points out that much attention has been given to the study of energy use in the residential and office sectors.

The present paper focuses on a particular building typology, not commonly addressed, to study user behaviour regarding energy use: school buildings. Most studies regarding school buildings focus buildings and systems features. A case-study approach is adopted to assess energy use in schools and gives special attention to identifying indicators and strategies to improve energy performance through users. The main focus is on understanding the triggers and explanatory causes for user behaviour with potential impact on energy consumption. According to Becker et al. [15] the information on energy consumption of school buildings is still very limited, especially in the Mediterranean region.

In the following sections the conceptual framework and proposed methodology are described (Section 2); the SMP and school cases are presented (Section 3); the school key performance indicators and user behaviour and management strategies are presented, compared and discussed (Section 4); the Key Performance Strategies are identified and briefly discussed (Section 5) and lastly, the main conclusions and future developments are highlighted (Section 6).

2. Methodology

2.1. Conceptual framework: Key Performance Indicators as a base to Key Performance Strategies

Multiple case-study analysis usually implies two main research steps [35]: (1) analysing each case *per si* and (2) comparing among cases. One possible approach for comparing cases is defining comparable indicators that allow for summarizing and comparing levels of performance. In the present case, two Key Performance Indicators were selected: energy use (electricity and gas, normalized by surface area) and CO_2 equivalent emissions (normalized by number of students). While the first selected KPI – energy consumption – expresses one of the stakeholders' main concerns and priorities regarding the schools' performance and its economical sustainability, the second one – the CO_2 emissions – relates to the problematic research question of the environmental impact associated with the trend of energy consumption increase in the schools. Because the KPI's are normalized and the building cases support the same function and use, the schools with a better performance can be used to set goals while the variation between cases can be addressed as a potential for efficiency improvement. Other KPI, associated with user comfort, can later be introduced and related with energy consumption to determine energy efficiency. For the present, the main focus is on energy use and management strategies. Two studies regarding Portuguese schools already report specifically on environmental parameters [4,19].

Research on the impact of organizational behaviour in energy use in the retail sector [27] concluded that the pure goal-setting approach (KPI) presented problems in motivating energy performance goals in the organizations. Moreover Gram-Hanssen [31] and Fischer [36] pointed out that electricity and heat consumption data, *per si*, are not enough for efficient and effective communication to stakeholders, namely the users. Jain et al. [37] provided evidence of such conclusions.

The proposed methodology defines the KPI's as a base for identifying Key Performance Strategies (KPS). The Key Performance Indicators allow for a quantifiable and direct performance comparison between the cases. The Key Performance Strategies, which result from the analysis of user behaviour and its potential impact on energy use, propose potential ways to achieve best case performances.

Fig. 1 presents a graphic scheme of the proposed methodology. This approach considers user behaviour and how their future actions are affected by the feedback from their previous ones as a relevant observational field for the study of buildings in energy-use performance. Fig. 2 presents such a concept, regarding user interaction with the buildings and systems, adopted from the Complex System Dynamics theory [38,39].

2.2. Methodological approach: case-study analysis

In the present case, the conceptual framework is applied to a multiple case-study comprising eight Portuguese public secondary