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Developing energy consumption benchmarks for buildings: Bank branches in Brazil

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ABSTRACT

The energy consumption of buildings is an area of increasing importance, and developing economies like Brazil must start to consider the energy performance of existing buildings. The publication of national energy benchmarks is a fundamental step for understanding energy consumption in commercial buildings and developing energy efficiency programmes. A voluntary data gathering initiative by the Brazilian Sustainable Construction Council (CBCS) is producing the data necessary to develop national benchmarks. A methodology for benchmark development is proposed, using both statistical data and energy audit data to benchmark end-use energy consumption, with the use of wet-bulb cooling degree hours for climate correction. Benchmarks and climate corrections are developed for the energy consumption of bank branches in Brazil. A simple linear regression analysis of data from 1890 bank branches in 57 different climates provides the energy consumption benchmark, while thermal simulation of building performance is used to validate the results and provide an end-use breakdown in the different climates studied. This work provides the foundation for further work to develop and publish national benchmarks in other typologies.

1. Introduction

1.1. Building energy benchmarking and labelling

Worldwide energy consumption continues to grow and maintaining energy supplies represents a large challenge for governments, especially in developing nations which require large investments in national grids and generation capacity to meet rising demand. Brazil's energy consumption for power generation is set to grow by 80% in the next 21 years [1] and currently over 40% of electricity is consumed in public, commercial and residential buildings [2]. Governments are setting carbon reduction targets, and as Brazil's energy grid brings ever more fossil-fuelled power plants online and carbon emission factors rise [3], energy consumption in buildings is likely to become a key area for controlling carbon emissions.

Benchmarking, rating and labelling the energy performance of buildings is widely recognised as one of the primary methods for improving energy efficiency and enabling transparency in energy consumption of buildings [4]. Some energy labelling programmes concentrate on predicting building energy performance at the design stage, but the application of these labels is limited to new buildings; in addition, many factors affecting energy consumption are likely to be outside the control of the building designers. These design stage energy consumption labels are generally known as asset ratings. When the in-use energy performance of buildings is measured, it can be compared with benchmarks for typical performance and used to create operational ratings. These are based on real results, rather than design simulations, and as such can be considered a truer reflection on the building's actual performance [5].

Since the 1990s, a wide variety of benchmarking systems has been developed in various different countries. The EnergyStar program in the USA provides ratings for commercial building efficiency, based on data from the Commercial Energy Building Consumption Survey (CBECS) [6]. The public reporting of these ratings became mandatory for large commercial buildings in New York as part of the Greener Greater Buildings Plan, and similar initiatives have since been adopted in several other states. Meanwhile voluntary adoption of EnergyStar ratings through the Energy Star Portfolio Manager tool has grown rapidly to more than 300,000 buildings, despite limitations of the data collection and

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benchmarking methodologies [7]. The European Energy Performance of Buildings Directive mandates the use of operational ratings for energy consumption in existing buildings. EU member countries have implemented the directive in different ways; for example, the UK has a policy requiring Display Energy Certificates (DECs) in large public buildings. The ratings given by DECs in the UK are based on energy consumption benchmarks published by the Chartered Institute of Building Services Engineers (CIBSE) [8], and generally developed in parametric methodologies like that used in the Energy Consumption Guide 19 (ECON19) [9], which describes benchmarks for office buildings. The National Australian Built Environment Rating System (NABERS) began as a voluntary rating system, but its successful implementation led to it being adopted as national policy; over 60% of eligible commercial floor space in Australia has already been rated [10].

These systems all have one common factor: they use building energy consumption benchmarks to rank energy performance and incentivise improvements in energy efficiency. Thus, the first step in any in-use energy labelling programme is to develop appropriate benchmarks for energy consumption, which can be used as the basis of the energy labelling programme.

The EPLabel project [11] proposes several stages in the development and implementation of a building energy label, or operational rating: collect data and calculate energy performance indicators, identify appropriate benchmarks, grade the energy efficiency, identify the energy saving measures, prepare the certificate and finally develop a building energy performance database.

1.2. Methods for developing benchmarks

A literature review reveals several different methodologies that can be used for benchmarking energy performance of buildings. Chung [12] identifies 23 references that describe development of benchmarking systems. Systems are classified into various methodologies:

- Simple normalisation is inexpensive and easy to implement, but cannot normalise for many building physical characteristics.
- Ordinary least squares method, generally using simple regression models. This method is commonly seen in the literature, and was used by Sharp [13] in research that later served as the basis of the Energy Star model.
- Stochastic frontier analysis separates error variables from inefficiency factors to provide more accurate measures of relative efficiency.
- Data envelopment analysis is a multi-factor analysis that measures the relative efficiencies of a homogenous set of buildings.
- Simulation of building performance is used to develop a model specific to that building, with known input parameters, and compare actual performance to the results of the simulation.

Although building simulation and data envelopment analysis are powerful tools for benchmarking a known dataset, they generally cannot be used where it is necessary to compare buildings outside the original dataset, as is the case in a public benchmark. Stochastic frontier analysis and ordinary least squares methods can be effective, but are highly dependent on a statistically relevant set of data that covers several different building characteristics.

Another review of building energy benchmarking methodologies is carried out in Li et al. [14], who divides the principal methodologies into black box, grey box and white box, according to the quantity of building-specific information available. Black box methodologies, including linear regressions, are generally identified as more useful for rapid modelling and convenience, which makes them the most appropriate for developing national benchmarks. White box methods, such as simulation, require significant effort for each individual building.

Martin [15], developing simple benchmarks for commercial buildings in South Africa, addresses some of the challenges of creating benchmarks in countries that have little history of data collection and no funds available for the expensive process of data collection adopted by CBECS and others.

Fumo et al. [16] uses benchmark models simulated in EnergyPlus to generate normalised energy consumption coefficients that can be used to predict the energy consumption of specific buildings. However, this work depends on the use of the building benchmark models published by the US Department of Energy; equivalent models have not yet been developed to characterise Brazilian buildings.

Hernandez et al. [17] developed benchmarks for schools in Ireland, based on the distribution of questionnaires and site visits, collecting detailed data on 46 buildings and simple data on 108. The benchmark data are used to propose a unified approach to developing asset ratings and operational ratings; the authors conclude that "being able to compare a building with the representative building stock. . . is a vital step for certification".

Lee [18] builds a regression model to predict building energy performance based on outdoor temperatures, occupant density and hours of rain. The predicted energy consumption based on this model is then compared to the actual consumption, and data envelopment analysis is used to evaluate energy efficiency of the buildings. This approach allows the impact of energy management to be isolated and evaluated individually. The approach is further developed and divided into scale factors of efficiency in Lee and Lee [19].

Other examples of benchmark development include Tereci et al. [20], working with simulation of residential buildings, Onut and Soner [21] using data envelopment analysis on hotel in Turkey, and Sabapathy et al. [22], working with regression analyses of office buildings in India. Wang et al. [23] identifies the limitations of multiple linear regression analysis where variables may show multicollinearity, and proposes the use of principal component analysis as an additional statistical tool for separating independent variables. Infrared thermography is used to validate this methodology on a dataset of 480 residential buildings.

Hsu [24] carries out detailed benchmarking analysis on the dataset of commercial buildings in New York, analysing the influence of major variables that might generally be considered in a regression analysis. Crucially, he finds that only two variables are statistically significant: building size and building-specific variation. Although his study was limited to large commercial buildings in New York, it encompassed a large array of buildings, with significant diversity. This finding would appear to strengthen the case for simple benchmarks with limited correction factors.

1.3. Developing benchmarks for Brazil

In order to be relevant and useful, benchmarks must be developed locally and represent national building stocks and performance.

In Brazil, widely used certification schemes such as Leadership in Energy and Environmental Design (LEED) [25] often require the use of some sort of benchmarking tool for in-use certifications. This has led to some buildings being benchmarked against EnergyStar standards. However, initial experiences by the authors and others have concluded that the North American benchmarks cannot be applied to Brazilian buildings with any modicum of reliability.

There is a severe lack of data on energy use in real buildings in Brazil; issues of confidentiality and unwillingness to share data have hamstrung previous efforts to develop national benchmarks through voluntary participation. Almost no studies have been