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Sensitivity analysis in building performance simulation for summer comfort assessment of apartments from the real estate market

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ABSTRACT

Overheating appears as a recurrent problem in apartments of the real estate market of Santiago de Chile, since their architectural design frequently does not incorporate passive cooling techniques. This situation is encouraged by a Thermal Regulation that allows extensive glazing surfaces in the apartments and that does not propose any criteria for limiting the risk of overheating. Nine apartment typologies were defined using the *k*-means clustering method from a database that contains 21,902 units. Sensitivity analysis was carried out by means of both global and local approaches, in order to identify the most sensitive parameters with respect to the summer comfort and the net effect of each single parameter, respectively. The results obtained suggest that the best performance in terms of summer comfort can be obtained from the combination of diverse parameters that would be significant in respect to the reduction of overheating, such as solar protection and night ventilation. In this sense, the approach proposed for this study not only allows introducing improvements in terms of summer thermal conditions according to the specific requirements of the apartment typologies, but also suggests the integration of attributes with the aim of being developed at the level of their value chain.

1. Introduction

The identification of housing submarkets is a matter of great importance. Typically, submarkets are defined as groups of similar entities, which are different from other groups (in other words, groups that are homogenous within and heterogeneous with respect to other groups). Accordingly to this definition, there have been significant developments for identifying and demarcating submarkets. These classification procedures can be divided into two categories: a priori definitions and data-driven methodologies [1]. *A priori* classifications use predefined and convenient criteria as the basis for defining submarkets, which in the real estate market analysis field is usually carried out based on supply price ranges. These traditional models are generally predicated on the assumption that the housing market can be characterised by a single price equation [2]. However, according to Lancaster [3], housing – considered as a consumer good – is not demanded for itself per se, but for the characteristics and attributes embodied within each real estate product. In this sense, data-driven submarket classification methodologies are based on statistical data analyses (including principal component analysis, partitioning algorithms and clustering methods) and can integrate a wide array of demographic, housing and locational attributes. Unlike a priori classifications – which are static in nature – these methods tend to be more objective and can capture the changing nature of housing submarkets.

The real estate market of Santiago de Chile can be considered as a representative example, in the sense that the land market is government regulated, the housing supply constitutes a semi-regulated market and at the same time is developed by the private sector. This is possible to observe, for example, through the presence of a very competitive market, strong marketing campaigns and complex real estate products, similarly to even more developed countries. In contexts like this, if variables like orientation and micro-localisation – which generally are very attractive for customers – are thought of as weak in a particular real estate product, the market is able to integrate more attributes or amenities to compensate it. For example, in a submarket focused on young couples, if a real estate product presents a disadvantageous location with respect to the metropolitan centres, their attributes will be increased, e.g. adding complementary public areas such as a swimming pool or gym, and/or improving the technical conditions of the apartments.

Santiago, as the capital city of the country, has a great importance, since it concentrates – at the same time – the 40% of the population [4] and 56% of the housing supply from the national real estate market [5]. In addition to this, the current National

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Thermal Regulation [6] constitutes the only mandatory building code that regulates building construction of the residential sector from an energy efficiency approach. In this sense, the situation of apartments in the context of the introduction of the requirements for walls and windows from the Thermal Regulation for Santiago appears as an interesting case study to assess, especially since there are no official studies about the impact – neither winter nor summer – that involve the increasing levels of thermal insulation in walls and at the same time the possibility to have extensive glazing surfaces. The case of the cooling season is particularly critical, since the Thermal Regulation was elaborated without any concern or recommendation related to the summer comfort and due to the own characteristics of the warm temperate climate of Santiago is expected that – if the corresponding measures are not applied – some level of overheating can appear. On the contrary, the national standard NCh 1079:2008 [7] suggests that for Santiago, glazing surfaces in eastern and western orientations should incorporate solar protection. However, as this standard constitutes just a recommendation and is not mandatory, in practice, solar protection devices have not been considered in most of the apartment buildings in Santiago, especially in the context of the real estate market. In this sense, if the aim is encouraging the use of this kind of shading devices in the real estate projects (and not as a post-occupation of the own users), the recommendation may be based on the specific characteristics of the different building typologies that may be found in the real estate market of apartments in Santiago. As a consequence, the first step to be able to assess the current situation of these apartments and the controlling measures that can be proposed in light of the results corresponds to the definition of building typologies in the context of the real estate market, as is also recommended by Bustamante [8].

In general, the housing market can be naturally separated by means of different indicators, such as supply price and living area. In the case of Santiago de Chile, real estate products are traded in terms of CPI-indexed units of account (UF).[1] According to this separation, supply prices can be disaggregated by ranges, which in the Chilean case are defined as: less than UF 1000, UF 1000–2000, UF 2000–3000, UF 3000–4000, UF 4000–5000 and more than UF 5000. However, this kind of approach – exclusively defined as a function of supply prices – forgets that real estate markets can compensate the lack of some specific attributes with other attributes or amenities. Therefore, a multidimensional approach is required allowing for the integration of a series of indicators and attributes with the aim of being developed at the level of their value chain. This study proposes a methodology based on multivariate statistical techniques from a database with information about 21,902 apartments of the real estate supply in the Santiago Metropolitan Area during the period 2004–2009. This database, which contains a total of 5 continuous and 17 categorical variables, was used thanks to *Portal Inmobiliario.com*, the most important search engine for property, apartments and houses for sale and rental in Chile [10]. According to this procedure, 9 apartment typologies were defined by means of a *k*-means cluster analysis and using the factor scores of a principal component analysis (PCA) as input variables for the procedure. By means of a robust statistical indicator, centroids of all typologies were estimated with the aim of defining representative apartments of the real estate market of Santiago de Chile.

In addition to this, it is clear that the thermophysical properties of materials, the occupant behaviour, climate data and internal gains represent some of the most important sources of uncertainty in the field of building simulation. Uncertainty and sensitivity analysis deals with this situation, since it can generate a great range of forecast values based on the probability distributions of the input parameters. Indeed, the probability theory allows conducting an uncertainty appraisal of the simulation output (dependent variable Y) based on the uncertainty of one or more input parameters (independent variables, $X = \{X_1, \ldots, X_n\}$) and where $Y = f_{(X)}$. However, most of the building energy simulation programs are deterministic, rather than probabilistic and consequently their results frequently are not expressed in terms of probabilities. On the contrary, the probabilistic approach requires a more complex process, since the parameters' quantification requires not only an assessment of the point estimate, but also an assessment of the uncertainty. Hyun et al. [11] suggest that the probabilistic approach delivers more meaningful information that one single, or even a series of deterministic simulations, whereas using only one deterministic simulation can easily lead to false conclusions. This situation appears as particularly critical when the analysis is focused on a cluster of cases – as the apartment typologies previously mentioned – instead of a single building case.

This study proposes a methodology where by means of a probabilistic approach based on sensitivity analysis techniques, the 9 apartment typologies proposed were analysed in terms of their summer comfort and risk of overheating. For the case of Santiago de Chile, this is particularly important, since it has been observed that passive cooling techniques – in many cases – have been misapplied and/or misunderstood due to the primarily aesthetic reasons for which they are used [12]. At the same time, the only official study in the national literature that has approached the subject indicates that 63% of the respondents declare that that the thermal sensation of their households can be defined in a range from "hot" to "slightly warm" and 45% of the registered households presents effective temperatures over 30 °C (considered as the average of the air temperature and the surface temperatures of walls) [13]. It can be also mentioned that this research is focused on the real estate market of apartments since this constitutes a niche that, despite that it is associated to a very significant segment of the middle-incomes population (in the last 5 years, the supply of apartments in Santiago have been always in a range between 30,000 and 40,000 units), has practically not been studied in terms of the impact on the thermal comfort. As the real estate market belongs to the private sphere, it is generally expected that most of their aspects (including the thermal performance of them) – independent of the mandatory building codes such as the Thermal Regulation – will be determined by the private market. Social housing, on the contrary, has attracted the public attention in recent years in Chile by means of different public and private initiatives, such as the publication of a design guide about the energy efficiency in the social housing [14], the Elemental project [15] and two architectural contests organised by the Ministry of Housing and Land Development in 2006 and 2007 about the architectural design of energy-efficient social dwellings. Therefore, it is clear that the study of the impact of passive cooling techniques in the real estate market of apartments of Santiago de Chile may represent an important contribution to the national state of art and even with respect to other locations in Mediterranean climates.

This article proposes a systematic approach to the application of passive cooling strategies with the aim of obtaining adequate conditions of summer comfort, avoiding the use of air conditioning and without detrimentally affecting the thermal behaviour during winter in apartments of the real estate market of Santiago. Consequently, passive cooling strategies that depend on the architectural design and/or the occupants' behaviour were studied. In this sense, from a total of 6 input parameters, a sample matrix of 140 samples was defined which were simulated for each

[1] 'Unidad de fomento' (UF) is an indexed unit of account used in Chile. The exchange rate between the UF and the Chilean peso is constantly adjusted to inflation so that the value of the UF remains constant. It has become the predominant measure for determining construction costs, values of housing and secured loans. UF 1 = US$ 48.3 [9].