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Life quality disparity: Analysis of indoor comfort gaps for Chilean households

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ABSTRACT

According to the last report of the Organization for Economic Co-operation and Development (OECD), Chile leads the iniquity ranking among the member countries. This inequality goes far beyond the income of a family or the movement between social statements. This work attempts to appreciate this gap in the life quality of the people, precisely in the context of the indoor environmental quality. The methodology involves the Predicted Mean Vote (PMV) for measuring thermal comfort, using the Predicted Percentage of Dissatisfied (PPD) as dimensionless index; and the CO_2 concentration as indicated by the ASHRAE-55 standard. The sample involves 20 households in the city of Santiago de Chile, distributed in 5 socioeconomically disparate communes. The National Monitoring Network (RENAM) was used as database, from which information of indoor environmental variables was obtained for 3 winter months. Based on the results, economic inequality is easily confirmed for thermal comfort aspects. A significant difference is shown for the cluster with lowest income, which presented the worst conditions. This difference is even more remarkable when the levels of CO_2 are compared. Finally, government policies should consider economic aspects in reducing the iniquity gap, jointly with air quality, energy efficiency and thermal comfort of houses.

1. Introduction

Life quality is a critical dimension to quantify the development of a nation. Measurement of life quality may integrate several variables, such as water access, life expectancy at birth, electricity access, income per capita, among others, which hinders the construction of a single objective metric (Pasten and Santamarina, 2012). Recent studies have found evidence of a correlation between energy consumption and economic growth (Saidi et al., 2017; Osman et al., 2016), as well as with human development (Pasten and Santamarina, 2012; Niu et al., 2013), however these correlations are far from being completely understood. An interesting point of view in the analysis of the role of energy into the life quality and the development of nations, is to consider the quality of the available energy in terms of its consumption efficiency, transportation, and conversion process. These factors can have a negative impact on life quality from energy systems with high levels of pollutant emissions and low efficiency, which might deteriorates the living conditions of people (Ray et al., 2016).

Energy sources used in Chile for heating vary by type and quality. This is evidenced in the National Socioeconomic Characterization survey (CASEN) from 2015, which found that for the capital city of Santiago, 50.7% of the energy used for heating comes from gas (in the form of natural gas and propane/butane mixture), 22.0% from kerosene or petroleum, 11.1% from electricity, 4.2% from wood and its derivatives, and finally 12.0% of the population has no heating source at all (Ministerio de Desarrollo Social, 2016).

The same survey shows for low socioeconomic households, that the primary source of heating is the cheapest available: firewood and kerosene, both of which have the highest level of pollutants in gas emissions (Jones, 1999). Their combustion systems tend to produce more carbon dioxide, particulate matter, sulfur dioxide, and nitrogen oxides, in contrast to heating by electricity or natural gas (Arashidani et al., 1996). The above implies decreased indoor air quality, and subsequently impacts the quality of life, in terms of indoor environmental variables such as particulate matter, humidity and pollutants.

In 2010, Chile was introduced as a member of the Organization for Economic Co-operation and Development (OECD). This organization gathers a total of 34 developed and emerging countries (OECD, 2015), where Chile and Mexico are the only Latin American representatives. The acceptance of Chile in the OECD was the result of the economic development in the last 25 years, where the average annual gross domestic product (GDP) per capita growth was 4.04% between 1991 and

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2012 (The World Bank group, 2017). Nevertheless, there is evidence of inequality gaps in different aspects of Chilean society, including those found in: life expectancy (Tejada, 2016), access and coverage of health services (Cabieses et al., 2015), school education (Claro et al., 2012), air quality and green areas (Fernández and Wu, 2016). Using the Gini coefficient to compare the inequality of wealth distribution, Chile has the highest inequality value of Gini coefficient within OECD (0.465), where the average value is 0.318 (Center for Opportunity and Equality (COPE), 2016).

One of the symptoms of this inequality is seen in Chilean households, which are not exempt from the social gap reflected by the Gini coefficient. There has been a significant increase in the social segregation of urbanizations over time (Borsdorf and Hidalgo, 2008), in addition to the rise in urban gentrification in Santiago López-Morales (2016). Currently there is a significant difference in construction quality, level of urbanization, and energy consumption for heating between different socio-economic sectors in Santiago de Chile Borsdorf et al. (2015). These factors present a potential for disparity in life quality and comfort across different socio-economical levels.

Several authors have studied thermal comfort in low-income housing to assess the life quality around the world. Pignatta et al. analyzed the winter thermal comfort of houses in Cyprus, emphasizing three different housing clusters according to socioeconomic income (Pignatta et al., 2017). Vilches et al. proposed a building retrofitting methodology (Vilches et al., 2017), which generates no energy nor economic savings, but impact on the people's life quality. Escandón et al. studied the simulated and measured thermal comfort in social housing in southern Europe (Sánchez et al., 2017), who focused mainly on energy consumption by evaluating simulations for thermal comfort. Filippidou et al. studied energy efficiency measures applied to the non-profit housing sector in the Netherlands (Filippidou et al., 2016), as well as how fast energy efficiency has evolved in the stock of non-profit housing in the Netherlands (Filippidou et al., 2017). The main difference between the studies mentioned previously compared to the Chilean case is the higher economic inequality gap observed (Center for Opportunity and Equality (COPE), 2016) and the extensive presence of cheaper combustion heating systems based on firewood or kerosene (Ministerio de Desarrollo Social, 2016). In this context, it is relevant to analyze the impact of heating systems on the indoor air quality (Kelly et al., 2016).

The aim of this work is to propose a methodology able to evaluate the household life quality, in order to improve governmental policies and reduce its disparity. The article is organized as follows: firstly, we make the selection for the indoor thermal comfort model and establish the key environmental variables (Section 2). A statistical description of them is performed for different communes of Santiago de Chile, using real data (Section 3). Then, the selected model is applied and results are presented using different schemes in Section 4. The discussions are addressed in Section 5, where recommendations for government policy makers approaches are suggested. Finally, Section 6 presents the main conclusions of the work and future researches guidelines are suggested.

2. Data

The information was obtained from the National Monitoring Network (RENAM), an initiative led by the Ministry of Urban Development (MINVU) and Fundación Chile (Ministerio de Vivienda y Urbanismo, 2017). The data was recorded by the Monitoring System of Environmental Variables (Sistema de Monitoreo de Variables Ambientales in Spanish, SMVA), measuring variables in different cities of Chile. The information registered is transferred to the main server, with a temporal resolution of 30 min. Later, the data is made publicly available and can be found on the RENAM on-line platform (Fig. 1).

For the present study, Relative Humidity, Internal Temperature, and Carbon Dioxide concentration data are used, and described as follows:

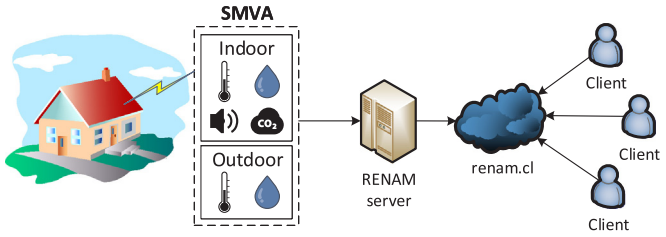

Fig. 1. Diagram of operation of the monitoring system in homes.

- Relative Humidity (HR): represents the amount of existing moisture in relation to the saturation humidity, expressed as a percentage. Its importance lies in the influence on the thermal sensation.
- Ambient Air Temperature (T): represents a fundamental parameter, because it has a strong influence on the thermal comfort of homes.
- Carbon Dioxide (CO_2): indoor concentration of carbon dioxide, used as a parameter to track the evolution of indoor environmental quality. The measurements consider carbon dioxide volume concentration inside the homes.

With the available measurements, a methodology is presented to determine the level of comfort in different dwellings in a set of selected communes of the city of Santiago de Chile.

3. Methodology

In this study, houses from different communes in the city of Santiago are analyzed based on the relative similar outdoor environmental conditions due to geographical location proximity. In order to characterize the existing socioeconomic gap, communes presenting a clear stratification in the income level of its inhabitants are selected (Garreton, 2017). The communes are grouped in three clusters, according to their level of annual income per capita, where cluster A corresponds to the highest income level and cluster C to the lowest income level. The income level information is obtained from the CASEN survey (Ministerio de Desarrollo Social, 2016).

The characterization of the social gap is made based on the thermal comfort measurements, which is related to the air quality. The former is obtained using measurements of the indoor ambient temperature and relative humidity, while the latter is analyzed through the CO_2 levels; however, these three variables have been shown to be strongly influenced by the activity of the dwellings' occupants (Szczurek et al., 2018). A profile is compiled to observe the behavior of each variable from June to August, to evaluate the life quality during the poorest environmental conditions of the year in Chile, corresponding to the winter season. We focus the analysis on this season in Santiago because of the following reasons: (i) Predominance of environmental warnings product of an elevated concentration of particulate matter released to the air (Ministerio del Medio Ambiente de Chile, 2017), (ii) low temperatures in winter (de Aeronautica Civil and de Chile, 2016), (iii) increased use of residential heating systems versus air conditioners (AC) due to its low cost (Schueftan et al., 2016).

Finally, a comparison was made between the variables according to the commune in which the dwellings are located, and how they relate to their economic income. The analysis of the measurements allows us to understand how to approach government policies and understand which variables to concentrate the efforts on, in order to reduce the inequality gap in the quality of life in Chile.

3.1. Indoor thermal comfort

A relevant aspect in the people's life quality is thermal comfort (World Health Organization and others, 2007), which is affected by several variables, such as energy efficiency of dwelling, occupation level, external weather, activity level and type of clothing of the persons