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Fuel Poverty Potential Risk Index in the context of climate change in Chile

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ABSTRACT

Public housing policies face a challenge in order to meet not only the right to housing, but also an affordable and comfortable use for them. In this context, most of the studies related to fuel poverty are based on a diagnosis of existing conditions, but there is a lack of information focusing on how to predict the risk of fuel poverty in future dwellings considering a context of climate change. This research develops an index to assist policymakers in the decision-making process during the early stages of social housing allocation. The analysis is based on the applicability of adaptive comfort, the influence of climate change, the urban context and the building features. Energy use patterns and the ability to pay utility bills have been also considered for social housing in the Central-South of Chile. After that, several future scenarios are discussed considering the probable income and energy inflation rates. The potential risk variables that influence the early stages of design are also discussed. The results reveal that the Fuel Poverty Potential Risk Index is an effective tool to select appropriate housing for the most disadvantaged and vulnerable segments of society, considering the future climate, income and energy price trends.

1. Introduction

Energy poverty appears as one of the main challenges for the upcoming decades when talking about energy policy. The objective of the UN´s Millennium Development Goals (Rehfuess, 2006) is to eradicate extreme poverty, thus improving living conditions and facilitating the path towards sustainable development. Neither this document, nor the United Nations Framework Convention on Climate Change (UNFCCC) deal with the so-called access to energy (Reddy et al., 2000). However, energy consumption levels that satisfy basic necessities may not be reached in developing countries (González-Eguino, 2015) due to a complex interplay of power (Thompson and Bazilian, 2014), politics and commodification, together with asymmetry regarding the management, generation, distribution and final consumption of energy (Brown et al., 2014). As an example of this, the population with access to electricity in African countries is 72% (Legros et al., 2009), and in some of them, the only feasible energy source is burning wood or charcoal (Mandelli et al., 2014).

In developed countries, electricity is not the only energy source and access to energy services is mainly guaranteed. However, public policies oriented towards the lower strata of society have been increasingly developed in countries such as the UK (Robert et al., 2012a) and the US, (Department of Health and Human Services (U.S.), 2010). They aim at dealing with the transformations of the energy sector caused by climate change and the phenomena of energy poverty (González-Eguino, 2015).

Climate change has been profoundly analysed because of its influence, amongst a variety of economic sectors. In the construction industry, which represents approximately 40% of the energy consumption caused by human activities (Pérez-Lombard et al., 2008; UNEP, 2012); these figures are expected to grow over the coming years (IEA, 2013). For this reason, This has become a matter of attention for both governments and research institutions over the last few years. Starting with the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which has recently published its Fifth assessment report (AR5) (IPCC, 2014), there have been numerous studies that focus on climate change, the increase of gas emissions and the scarcity of natural resources. Along this line, sundry prediction models have been generated for various climate scenarios (Jentsch et al., 2008). Most of these models have been developed in the United Kingdom (Mylona, 2012), although they have increasingly extended throughout the international framework (Guan, 2009; Jentsch et al., 2013). Currently, the IPCC, supported by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), which is the most widely accepted organization in this matter, envisages multiple emission scenarios for the near future (IPCC, n.d.). According to several

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Nomenclature

AA	Apartment gross surface area
AL	Apartment location within the apartment block
AMEC	Average monthly energy consumption
AMECAC	Average monthly energy consumption using adaptive comfort
AEN	Asociación Española de Normalización
AR5	Fifth Assessment Report
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BT1	Tariff 1 for low voltage electricity
CASEN	Chilean national socioeconomic survey
CCS	Sustainable Building Code
CEN	Comité Europeo de Normalización
CO_2	Carbon dioxide
COP	Coefficient of performance
CLP	Chilean peso ($)
CTD	Technological Development Corporation
D	Distance from the shade element (m)
D_n	N decile
D_1	First decile
D_2	Second decile
D_3	Third decile
D_4	Fourth decile
DBT	Dry Bulb Temperature (C)
E	East
EC	Energy consumption (kWh)
EC_R	Real consumption (kWh)
EC_S	Simulation consumption (kWh)
EC_{SC}	Average monthly cooling consumption from the simulation (kWh)
EC_{SE+L}	Average monthly average consumption of equipment and lighting from the simulation (kWh)
EC_{SH}	Average monthly heating consumption from the simulation (kWh)
EER	Energy efficiency ratio
EN	European Norm
EPBD	Energy Performance of Buildings Directive
EPW	EnergyPlus Weather
EU	European Union
FP	Fuel poverty
FPAC	Fuel poverty adaptive comfort
FPI	Fuel poverty index
FR	Form ratio
FPPRI	Fuel poverty potential risk index
GCM	Global Climate Model
GHG	Greenhouse Gases
GHR	Global Horizontal Solar Radiation
H	Height of the shadow element (m)
H_t	Total hours of the study period (h)
H_d	Unoccupied hours of the study period (h)
H_c	Hours occupied in thermal comfort applying category III of the EN 15251:2007 norm pursuant the limits of Eqs. (3)–(5) (h)
HadCM3	Hadley Centre Coupled Model, version 3
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
INE	Instituto Nacional de Estadística de Chile
IRE	Inflation Rate Energy
IRI	Inflation Rate Income
LIHEAP	Low income home energy assistance program
LBL	Lawrence Berkeley Laboratory
MDS	Chilean Department of Social Welfare
MINVU	Ministry of Housing and Urban Development
N	North
NE	Northeast
NEA	National Energy Action
NO	Northwest
O	Orientation
OECD	Organization for Economic Co-operation and Development
OGUC	General Urbanism and Building Ordinance
P	Energy price ($/kWh)
P_C	Energy price for cooling ($/kWh)
P_{E+L}	Energy price for equipment and lighting ($/kWh)
P_H	Heating fuel or energy price ($/kWh)
PPI	Progress out of Poverty Index
O	West
RH	Relative Humidity
S	South
SCATs	Smart controls and thermal comfort
SE	Southeast
SEDI	Sustainable Energy Development Index
SL	Coastal South
SO	Southwest
TI	Threshold income
U	Thermal transmittance (W/m^2 K)
UK	United Kingdom
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
WMO	World Meteorological Organization
Θ_{imax}	Upper limit of indoor operative temperature in Category III (°C)
Θ_{imin}	Lower limit of indoor operative temperature in Category III (°C)
Θ_{rm}	Running mean outdoor temperature for a specific day considering the daily mean external temperature of the 7 previous days (°C)
μ_{Dn}	Mean deviation
σ_{Dn}	Standard deviation
σ^2_{Dn}	Variance

research projects (Kalvelage et al., 2014; Rubio-Bellido et al., 2016; Wang and Chen, 2014), patterns for energy demand and consumption may be altered by climate change; therefore, they should be taken into account when devising schemes for energy supply and should also be carefully considered in order to prevent energy poverty.

Energy poverty, commonly linked with lack of access to energy sources and/or a deficient coverage of energy needs may be quantified in different ways, mainly considering high prices of fuel or energy, low building performance and low level of income.

The origin, evolution and discussion about the definition of energy poverty can be found in some key publications in this field (Robert et al., 2012b). For the sake of clarity in the discourse, the definition given by B. Boardman, which is considered a key text in the fuel poverty debate, is adopted in this manuscript (Boardman, 1991). Boardman states that "fuel poverty" can be defined as "the inability to afford adequate warmth because of the inefficiency of the home"; the threshold for affordability is established at 10%, twice the median household expenditure on fuel in 1991 (Liddell et al., 2012). Since then, despite the 10% threshold being broadly used as a general criteria to evaluate fuel poverty (Legendre and Ricci, 2015; O'Sullivan et al., 2015; Santamouris et al., 2013; Walker et al., 2014b), many authors have raised their concerns about the real significance of this figure. Methods