Influence of the user behaviour in the total energy consumption on social housing in Chile

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ABSTRACT: Previous studies have revealed significant differences between the theoretical and real energy consumption of buildings. These differences can be associated with the use of space heating and ventilation systems. The main difficulty is to simulate manual operation of the heating and ventilation system and to achieve results that approximate reality. The aim of this paper is to present the initial stage of the generation of a calculation model based on the space heating energy use. The generated model, works with free temperature (floating). It incorporates some of its occupants practices related to the use of energy systems. Subsequently, the results are compared with the information obtained in dwellings studied. This paper presents the model and its validation with the first 7 houses. Using a classical model, significant differences were obtained. By contrast, with the proposed model the difference is much smaller, when compared with experimental data. In the future, it is expected to identify the variables and parameters that have the min influence on the model. Thus, it is expected to achieve the calibration of the model and future generalization to other dwelling types.

1 INTRODUCTION

According to Annex 53 of the *International Energy Agency* (2008-2012), there are six factors that directly influence the energy consumption of a building. Three of them are related to the structure and location of the house (climate, building envelope and service building). The other three are related to the influence of the user behavior within buildings (occupants' activities and behaviour, indoor environmental quality provided and the operation and maintenance of the building).

Currently, several studies (De Groot et al., 2008; Guerra-Santin, 2011; Audenaert et al., 2011) show that the behavior of people greatly influences the energy use within buildings. The differences that often exist between real energy consumption and theoretical energy consumption "sometimes are misunderstood and often have more to do with the role human behavior than with the building design itself" (Annex 53, ECBCS). "These discrepancies may pose variations from 30% to 100%, in certain cases" Azar & Menassa (p.1, 2012).

According to researchers such as Guerra-Santin & Itard (2010), ventilation and space heating systems, produce strong influences in the final energy consumption of households. Although the systems can be controlled mechanically, the building occupants are who finally take the decisions of its operation. The influence that the occupants made on ventilation and space heating systems will depend on: the characteristics of the heating equipment, the type of used fuel, the family income, the housing characteristics, the customs, etc.

In the current literature, it is possible to find a great number of tools used to analyze and predict the buildings energy consumption (Yu et al., 2010). Among these tools, the dynamical energy simulations models are quite extensive used and has been the basis for a lot of calculation models. These models are created to interpret reality and to obtain more reliable results.

The models are based on main factors that influence energy consumption, such as the ventilation system and its control by building occupants, the space heating system, the lighting systems, among others (Muratori, et al., 2013; Bekö et al., 2011; Kialashaki et al., 2013). However, these models are not always easy to use and / or often require a large amount of information for its operation.

The aim of this paper is to present the first results of a study conducted in Chile. This study seeks to create a model that integrates human behavior patterns of users in the use of space heating and ventilation system. Behavior patterns were collected through surveys of users to a set of social housing. Subsequently, these patterns are incorporated into the model in TRNSYS and EES environment.

The surveys were carried out during the winter of 2011 and 2012.

The study aims to narrow the gap between the consumption of energy for heating theoretical and real, in low-cost housing.

Identify the actual consumption in this type of housing could improve future decision making in energy efficiency programs.

The article is presented as follows. The second section presents the national context and the data used. The third section presents the methodology regarding the calculation of theoretical and real energy consumption. The fourth section describes the results obtained by the models calculations presented in the previous section. Finally, in section five are given the conclusions drawn from this analysis.

2 BACKGROUND

2.1 *National context*

The study area comprises the central-southern Chile. In this area there are 4 of the 7 thermal zones defined by the government of that country (Fig. 1). In general, the climates present in the study area are not rigorous, but anyway it is necessary to use heating in the months of winter.

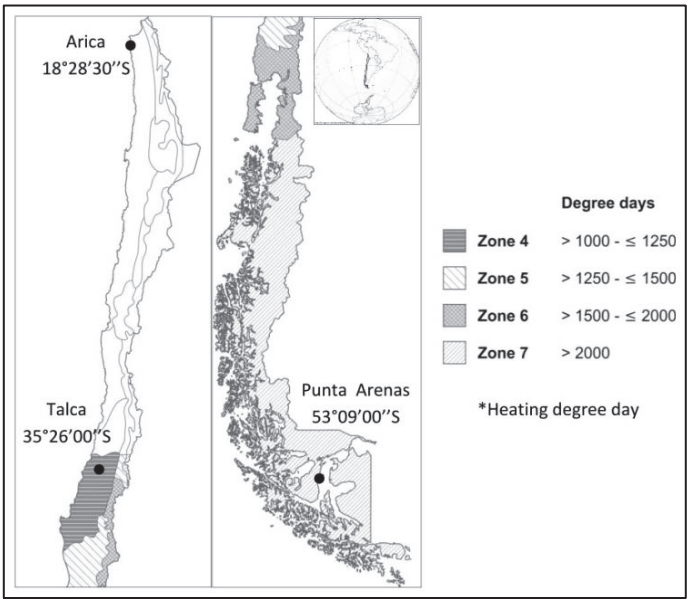

Figure 1. Distribution of the study area.

Social dwellings are very similar between them. They are usually one or two floors and their average size, in general, does not exceed 60 m ². A high percentage is attached to a common wall (Fig. 2). The materials commonly used for the walls are brick (14 cm thick) and wood (12 cm thick).

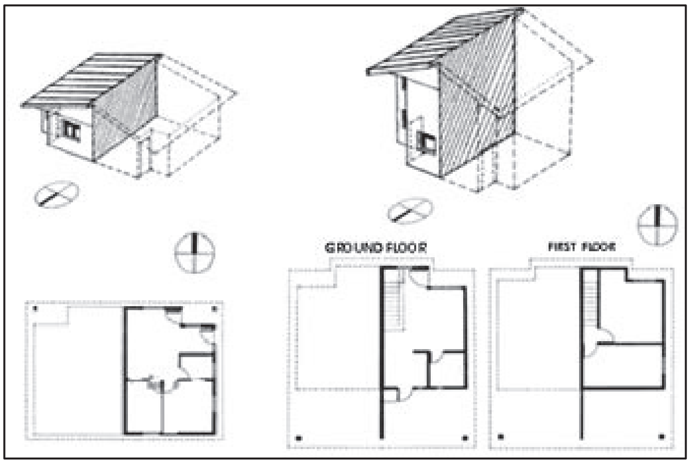

Figure 2. Typology of social housing in Chile.

Not all households have an adequate thermal performance in its envelope. Table 1 shows the minimum values provided by law of this country in relation to dwellings envelope built since 2007.

Given the physical characteristics of housing, low income of their occupants and the high cost of fuel, heating systems used are rather diverse.

Table 1. Minimum values for U - value in Chileans residential buildings.

Zones	Roof*	Walls*	Ventilate Floor*
4	0.38	1.70	0.60
5	0.33	1.60	0.50
6	0.28	1.10	0.39
7	0.25	0.60	0.32

* U [W/m²K]

2.1.1 *Heating systems*

The percentage of Chilean housing that has a system of decentralized or localized heating is quite high (Fig. 3).

Owners must purchase their own heating systems, which will depend on their needs and costs associated with its use. Usually the amount of heating device in homes does not exceed the unity.

Heating equipment used in this type of housing possess special characteristics which are presented in Table 2.

The equipment, for the most part, do not have thermostat. Therefore, the temperature inside the housing is directly related to the management performed by occupants on the heating equipment.

The high fuel costs and low family income cause that the occupants of these houses restrict, in some degree -usually high- their use. This produces that the occupants generally do not maintain the required comfort temperature inside the dwelling.

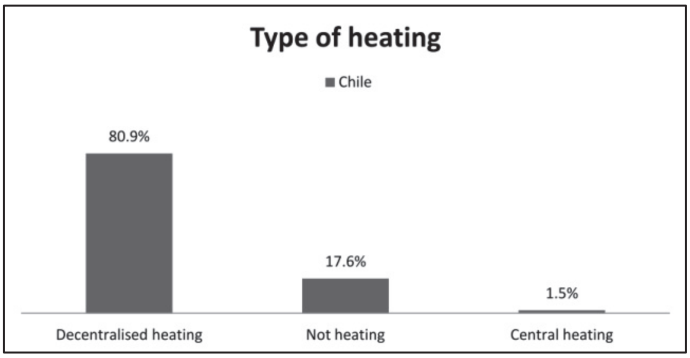

Figure 3. Distribution of heating along country.

Table 2. Heating equipment description.

Heating equipment	Description
Firewood salamandra	Old and inefficient cast iron stove
Controlled combustion fireplace	Fireplace that has the ability to regulate, manually, the entry of air to the combustion chamber. This seeks to save on fuel.
Wood cook stove	Cast iron equipment that serves two purposes simultaneously: food preparation and space heating.
Gas or kerosene heater without a chimney	This is a stove that runs on butane gas or kerosene. Normally the heaters are portable and expel combustion gases directly to the interior environment.
Electric	Device that produces heat energy directly by electricity (Joule effect).

At national level, the use of fossil fuels is important. However, in the study area, firewood represents around 90% of the use for heating, followed in importance order by coal, gas and kerosene.

2.2 *The database*

The data collection was conducted during the winters of 2011 and 2012. The database considers housing information before and after being submitted to a thermal reconditioning (improving the insulation of roof, walls and / or windows).

Data collection was conducted through field measurements and survey's application to the occupants. Measurements made correspond to: temperature, humidity, air tightness (blower door test) and thermography. Through surveys, information was obtained concerning: energy consumption (heating and general), equipment and fuel, energy usage patterns, ventilation patterns, habitability, internal loads, among others. Since the use of heating systems is important, information relating to: the type of heating equipment, the type of fuel used and the heating patterns, is included.

From the data collected in the field, actual energy consumption in each of the dwellings studied is obtained.

3 METHODOLOGY

3.1 *Energy consumption, according to surveys*

As mentioned above, firewood consumption is very high. This fuel consumption is difficult to measure, given its special features. Examples of this, are the units in which is acquired (m^3, chips, bags, trucks, among others) and humidity which may possess. The latter is directly related to the calorific value of the fuel.

Given the above, the determination of the fuel consumption from the field data may be performed based on three independent approaches. Thus, the results provide a more solid base in relation to actual consumption indicated by users in these surveys.

The survey was made with the objective of determining the energy consumption for each of the dwellings. The questions to obtain this consumption are related to:

- The expenses incurred by the family when heating the dwelling.
- The amount and types of energy used during the heating period.
- Number of hours per day and number of months that heating stays lit for each year of evaluation.

Upon completion of the surveys, the results are reviewed individually and together. Thus, extreme or non consistent data is check.

The first calculation is made based on the money spending declared by families in the heating energy used. This spending is carried to energy by each fuel (considering prices of fuels) and then converted to kWh from the calorific value of the energy used. The calorific value also depends on the humidity of the firewood used, which is also obtained from different inquiries in the survey. This process gets the first housing consumption.

The second energy is obtained based on the actual consumption of declared fuel. This is multiplied by the calorific value to get the energy.

The third way is by using a formula that considers the number of hours of use, the number of months, the type of equipment and the power level.

The latter methodology is given a lower weighting for the final result, because the results obtained from this approach are less accurate. This is mainly due to the inability of people to clearly define the number of hours of use of the equipment. Therefore, this approach is generally used only as a check. In addition, it should be noted that it was only applied to equipments using different fuels to firewood. This given the difficulty of estimating the power dissipation in partial load regime.

The results obtained here will be used to evaluate subsequent analyzes.

3.2 *Energy Simulation in dynamic conditions*

Nowadays energy simulation software available, quite effectively integrate a large number of parameters related to behaviour patterns of the occupants. However, many of these parameters tend to be ideal and / or standard, which is not always representative of all realities. Given this, it is necessary to find alternatives to help strengthen, in some cases, the gap between theoretical and actual consumption.

3.2.1 *Energy evaluation by a Classic Model*

Currently, the energy simulations are not only used to evaluate the performance a building would have a under certain conditions. They can also be used as a predictive tool in those cases that have the necessary input information.

A Classic Model considers parameters that in most cases have little variability, compared with reality. Parameters such as: air changes, the indoor temperatures and the power in which heating equipment are actually used are considered as constants. This is due to the difficulty of obtaining more accurate data.

To determine the difference between what is obtained in the field (actual energy consumption) and what is calculated on a common energy simulation (classical model) the calculation is made for the same housing under the following conditions:

• Ventilation: one air changes per hour

• Indoor temperature: 21 °C during the heating use. This corresponds to the temperature of comfort with poor housing insulation and therefore with relatively cold walls. The heating period corresponds to winter months.

• Heating System Performance: 70%

As above, the heating system would correspond to a wood stove. Thus, the yield calculated for this type of equipment is estimated at 70% (see section 3.2.2).

To carry out the simulations is used TRNSYS.

3.2.2 *Energy evaluation by a Proposed Model*

In Chile, as indicated in point 2.1.1., heating systems do not possess control systems and the start, the modulation and the shut off of heating, are very variables and depend on several factors. These factors are related to the amount of time users spend within their homes, the age of occupants, types of heating systems, the powers of the equipment used, and the cash income of families, among others. The factors related to the occupants have direct impact on the number of hours that heating is on. For example, if there are infants or old people, there is a high probability that the heating system runs longer than in the case of a couple who works outside the home during the day. Furthermore, the use of heating will also be constrained by the cost associated with its use.

Given the small size of the houses and the high power of the wood heating equipment, if manual control is neglected, the temperature inside the house can rise quickly (e.g. 24 °C for a wood stove). This was also checked with measurements. Whereas in other cases the internal temperature of the housing did not exceed 17 °C due to insufficient power of localized gas heater. Furthermore, it should be noted that the ventilation is effected by opening and closing windows, as the needs of each family owns.

The effect of this behavior, in the national context, makes heating consumption varies approximately between 10% and 130% of the consumption of energy that would have with a conventional control system (classical model). This range is delivered in general, but it is possible to find cases where the results exceed these values.

To model this form of heating use, dynamic simulation software for buildings - in this case TRNSYS – is employ, working on the floating temperature mode, i.e. no fixed interior temperature. Both, air changes and heating systems operations, work on a separate model (in EES environment also using TRNSYS equations).

The model of human behavior defines heating powers hourly in terms of a number of variables and adds them in TRNSYS as internal loads. These variables regard: the defined heating period, heating hour daily, internal temperature, domestic profits of each house (including from teams and individuals), volume of households simulated, and air changes per hour, among others.

These homes have only minimal air extractions surfaces necessary for bathrooms and kitchens (natural extraction). Ventilation is done manually (opening and closing windows) according to user need. This is a practice that users in this country conducted both in winter and summer. These air changes per hour are calculated by the hours when the windows are kept open.

The times and periods when the heating is available, are derived by the occupants statement in the surveys.

The power levels are defined based on a percentage of the equipment rated power, for different levels of housing operating temperature depending on what the user says and heating equipment available.

Below, Table 3 shows an example of a case of correspondence between the indoor temperature and the percentage of rated power input, to a wood stove.

This implies that if the operating temperature of the dwelling is 16 °C during the period of heating, the model will interpret the use of the equipment at maximum power (7 kW in this case). When the internal temperature reaches 17 °C, the model assumes a decrease of the nominal power by 35%. In practice, the user manually restricts the airflow to combustion.

Table 3. Description power levels of a firewood equipment.

Power level	Temperature Control
P0 = 0	T0= 23 °C
P1 = 0.3 N	T1= 20 °C
P2 = 0.65 N	T2= 17 °C
P3 = N	T3< 17 °C

N: Nominal heating power of the equipment

Thus, when the internal temperature reaches 23 °C, the model of human behaviour assumes that the heating is turned off.

The values in the table above depend on the heating system to use, but also depend on a number of other factors such as energy costs, socioeconomic status, individual preferences, and household composition, among others.

The model is developed in several stages. At this early stage, is based on surveys of the dwellings where people answer about the heating patterns, hours of use of heating, heating system types, levels of comfort, energy consumption, among others.

This information is used to feed the model, i.e. heating power dissipated in relation to the existing operating temperature (calculated). Also the results of assays for characterizing the tightness pressurization housing are use for calculating ventilation. After, the simulations are performed and compared with the measured temperatures and energy consumptions reported.

The resultants include a lower level of model correction, based on the available results. However, this results correction is not made with a systematic analysis, as it is expected for the next page. For example, the heating power considered (based on results) is corrected when it indicates that is working on medium power, but there is not comprehensive and systematic analysis of this variable.

Note that the results are also compared with reported feelings of comfort, average temperatures and calculated energy consumption (from surveys). This allows tuning and validating the model.

The efficiency used for each heating equipment is:

- 100% efficiency for gas and kerosene heaters without a chimney
- 100% efficiency for direct electric heater
- 50% efficiency for wood cook stoves
- 70% efficiency for wood stoves

4 RESULTS

In this section, is shown the analysis and results for a set of 7 houses, located in the study area. All dwellings are low cost houses and do not exceed 70 m^2. Next, Table 4 shows the main features. The aim is to determine the percentage value of the discrepancies between the calculated data field (Surveys) and the data obtained by a simulation with a Classic Model (CM) and the Proposed Model (PM).

Figure 4 and 5 show the results obtained for the three methods.

Table 4. Characteristics of dwellings analyzed.

Houses	m^2 built	city	thermal zone
V01	45.9	Talca	4
V02	57.3	Talca	4
V03	65.0	Sn Pedro de la Paz	4
V04	62.0	Sn Pedro de la Paz	4
V05	67.4	Valdivia	5
V06	46.1	Pto. Montt	6
V07	66.7	Coyhaique	7

Figure 4 shows the total annual consumption per m2 obtained for 2011, i.e. for thermal reconditioning before the study dwellings

The average total annual energy consumption 2011 obtained, according to surveys, is 134 kWh / m^2 year. For the Proposed Model and the Classic Model are 133 kWh / m^2 year and 333 kWh / m^2 year respectively. It should be clarified that such a, small difference between the first two digits is rather a coincidence, as expected differences in the order of 10% or more.

Moreover, Figure 5 presents the energy consumption when thermal reconditioning work had been completed.

The average total annual energy consumption 2012 obtained, according to surveys, is 103 kWh/m^2 year. For the proposed model and the standard model are 97 kWh / m^2year and 276 kWh / m^2 year respectively.

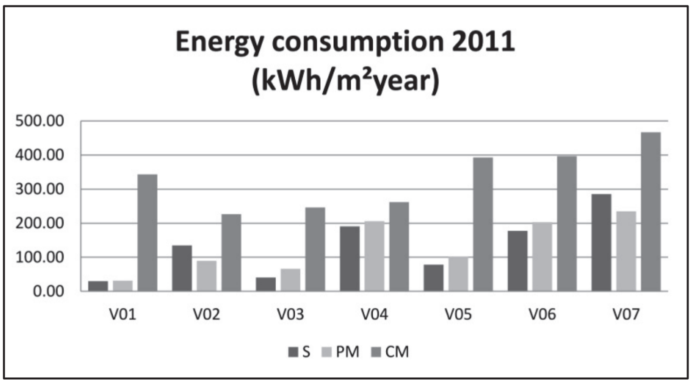

Figure 4. Comparison of total energy consumption for three different methodologies.

When comparing the averages of all the homes, it will find that difference between CM and S is around 300%. However, the difference between PM and S is about 10% only.

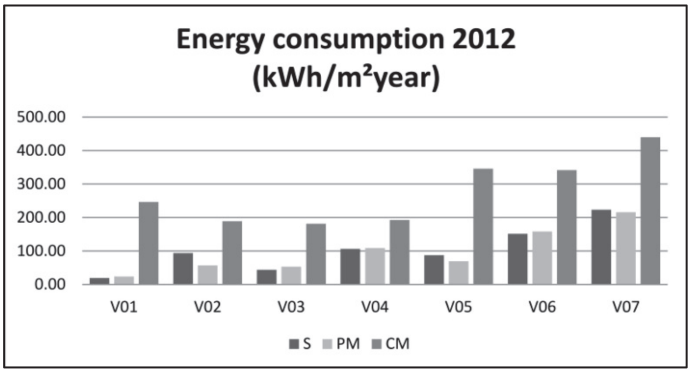

Figure 5. Comparison of total energy consumption for three different methodologies.

5 CONCLUSION

In this paper, the authors present a calculation model that aims to narrow the existing differences between the theoretical and actual energy consumption. According to the literature, this difference is related to the occupants make use of heating and ventilation systems.

This document shows the link between user behavior and space heating in those homes where its use is higher (central southern Chile).

The proposed model seeks to integrate the behavioral patterns of occupants, in relation to the use of heating energy. This is to obtain information closer to reality.

In the Proposed Model, the internal temperature is a result, not an input. Considering the internal temperature, the Model define if is necessary or not the use of heating, according to the expressed needs of occupants.

This new way of simulating housing, produces a strong decrease in the difference obtained between the proposed model and the experimental data. While the classic model still has a large difference compared to the same experimental values.

The previous model allows more precise analysis made it really consume social housing located in central southern Chile. This fosters future decisions regarding energy efficiency to these homes. All this contributes to increasing the quality of life of the people and development of this country.

However, further research is needed in order to obtain a general model, which allows it to be used without the need for a large amount of field data, like is currently the case.

6 ACKNOWLEDGEMENTS

This article was made in the context of the development of a doctoral thesis at the research centre *Architecture et Climat* of the Catholic University of Louvain, Belgium.

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