Diagnosis of Physical Quality of Existing Social Housing without Thermal Considerations in Chile

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ABSTRACT: This study is part of a main goal, whose aim is to improve the physical quality of the construction of those social housing that were built before the Chilean Thermal Regulation (TR). To achieve this objective, four social housings were selected as case studies. These houses represent a vulnerable sector of south central Chile and were the subject to a physical-constructive diagnostic. The diagnosis was based on three methods: in-situ measurements, dynamic simulations and user perception. The in-situ measurements were: a test of indoor and outdoor temperature, thermal flow of the perimeter wall and windows, and a blower door test to measure the exterior air infiltration. The infiltration performance is a serious problem in the Chilean construction, and represents a major energy loss. In spite of that is not considered in the current TR. In this study it is shown how the infiltrations influence the energy efficiency of housing and other aspects, such as the quality of indoor air. Dynamic simulations were complemented by the experimental results to bring the simulation near to reality and get reliable outcomes. For the case studies simulations were set certain inputs that are not standardized in Chile: the minimum of natural and artificial ventilation, internal gains and a comfort temperature range for summer and winter, among others. The result of the free running simulations was the temperature frequency, which throwed knowledge on how many hours the housing wasn't in comfort. Then, with heating and cooling systems included, the delivered results were: energy demand, influence of elements that lose more or less energy, the total sum of ventilation, infiltration, etc.

Keywords: Social Housing; Blower Door Test; Building Energy Simulation; Infiltration Airflow Rate

INTRODUCTION

Worldwide, buildings are one of the major sources of energy demands and of carbon dioxide emissions into the atmosphere. The heating implies among 40% and 60% of the average house energy consumption. The residential sector is responsible for 40% of CO2 emissions received by the planet [1]. The energy consumption for heating and cooling of buildings is the most influential factor in the environmental impact [2].

Since the 90s, the electrical energy demand in Chile showed sustained growth [3]. The CPR sector (Commercial, Public and Residential) represents 27% of the country's energy consumption; the residential sub-sector is responsible for 84%, followed by the commercial (13%) and the public (3%). Hence, the residential sector consumes 23% of the total energy consumed by the country [4].

Countries with energy dependence, as Chile, should ensure optimal use of energy resources, using less energy without sacrificing comfort or economic activities [5]. Reducing the energy consumption in a building is fundamental factor to attenuate dependence on energy imports.

Nowadays the energy for heating is the greatest demand in the energy distribution for Chilean residential sector. 56.3% of the total energy consumed is for heating, followed by the use of hot water (17.6%).

The higher consumption to heat a dwelling (indiscriminate fuel type used) acknowledges the need to reduce fuel demand, and the urge to propose different strategies to achieve indoor comfort without the need to assume high economic costs to obtain it. Because of that, this research studies energy and environmental existing houses retrofitting, which have been built prior to the implementation of thermal regulation (TR) in Chile (2000), i.e. those who did not had energy considerations in design and construction.

The refurbishment of existing houses with energy-environmental strategies will reduce the energy costs for heating, among other issues.

RETROFITTING OF EXISTING SOCIAL HOUSING

In Chile there are thousands of families who are living below the line of "fuel poverty". This kind of poverty, according to the author Sung Hong [6], is caused by a combination based on low incomes and high energy costs, in addition to energy inefficiency or poor thermal quality of the house envelope. Most of these families do not spend a significant percentage of their income on heating to reach interior comfort. The reason is not that they like to live in a cold house, but they prefer to spend their money on other priority needs, such as eating, moving or dressing [7].

The energy consumption in vulnerable sector is not sufficient to achieve the ideal indoor temperature conditions during the winter. The comfort inside these homes is only for a few hours.

It is for this reason that this research addresses the issue of social housing, which are also built on a massive scale and if they are retrofitted, the impact is perceptible at a country level.

CASE STUDIES

In order to determine the houses that would be studied, it were used the building certificates of one of the most vulnerable communities in the region (Hualpén). It was use dwellings which classified as social housing and were built before 2000.

The information was organized in a spread sheet where it was indicated: the name of the neighborhood, year of construction, clustering type (detached, continuous or isolated), floor area, number of levels, materiality, number of dwellings and overall valuation.

Finally, four housing were selected from the existing constructed stock (Table 1).

Table 1: Houses selected as case studies.

Neighbourhood	*Year*	*Type*	*Area m²*	*N° floor*	*Materiality*	*Total houses*
Cabo Aroca	1989	Semi-detached	30.36	1	Framework Wood	207
Peñuelas II	1990	Semi-detached	44.42	1	Brickwork	446
P. Aylwin	1993	Continuous	40.38	2	Brickwork	249
El Triangulo	1991	Semi-detached	36.00	2	Framework Wood	214

Figure 1: Images of the case studies.

DIAGNOSIS

Diagnosis of physical quality of housing is considered as a post-occupational evaluation (POE), which is a tool designed to get more information about the performance of the existing project. With this information it is possible to propose solutions that can be beneficially applied in future projects [8]. In this research is a technique used to understand and learn from the real performance of the building, and then propose performance-based improvements, which are based on reliable data.

Basically, POE consists of learning from the results rather than predict events and be based on results of other cases. It is better to have a reliable backup and to generate feedback through a retrospective vision.

Experimental Diagnosis

This technique provides a mean to evaluate physical properties of the current state-building of housing, as well it as is monitoring of external conditions change. In resume, these measurements provide a real documentation of the building physical conditions [9].

Measurements made during the winter in the four houses were three: flowmetry of a window and a wall, indoor and outdoor temperature and air tightness test by pressurization (Blower Door Test). The first two can determine the real thermal transmittance of building elements (Table 2), while the latter is used to determine the unwanted infiltration airflow rate of the house envelope and define the actual level of tightness.

The data obtained are used as reliable complementary information in energy simulations. This input seeks to approach the reality of demand and marginalize the estimates [10].

Table 2: Values obtained from the experimental diagnosis.

	T° inside °C	**T° outside** °C	**U value Wall** W/m²K	**U value Wall TR** W/m²K	**U value Glass** W/m²K	**U value Glass TR** W/m²K
Cabo Aroca	12,56	7,21	1,76	1,7	5,54	2,56
Peñuelas II	11,95	5,70	2,35		5,35	
P. Aylwin	15,5	13,2	2,92		5,49	
Triángulo	8,75	2,68	1,44		5,33	

**TR= Thermal Regulation in Chile*

As shown on Table 2 all the walls, except those of El Triángulo, are out of the maximum range of thermal transmittance that is established by the TR.

Table 3: Infiltration airflow rate.

	Cabo Aroca	**Peñuelas II**	**P. Aylwin**	**Triángulo**
Infiltration airflow rate (1/h)	2,59	1,67	0,63	1,80

The methodology to calculate the infiltration airflow rate was to subject the n50 values that were obtained from blower door test, to the calculation that provides the AIVC for cases with average protection (n50/20) (Table 3).

Energy and Thermal Simulations

The aim of simulating the case studies is to predict the energy demand for heating and cooling, among other performances. The theoretical results of energy use (by calculation) can be very different to the real demand. Because of this, the information obtained from the three methods were compared and complemented.

For thermal simulation it was used the software Design Builder (DB). DB operates with the calculation engine of Energy Plus, which ensures more realistic results.

In order to simulate, the data were grouped according to three sets: occupant behavior, building design and exterior conditions. For each of them it must be specified different variables, not all of which are standardized in Chile. Some of them remained in the same state or with the same value for all the case studies, meanwhile, other physical properties were varied between housing.

The first variable to consider was the temperature range to be in comfort. Considering that there are several factors that affect this definition, it was necessary to use an adaptive model of thermal comfort. This range occurs under a combination of thermal variables (temperature, humidity and air velocity) in this particular geographical location.

One of the most used adaptive models of thermal comfort is the one suggested by ASHRAE Standard 55 [11], whose specify the combination of interior thermal factors of the building and the users own personal factors. This combination will produce acceptable thermal conditions to the majority of occupants within a space.

So as to set the comfort temperature range, two periods were defined:

- *Cold Period*: April to September. Months where users need heating and those habits change (use more clothing, for example). Hence, it is possible to reduce the value of the temperature range.
- *Temperate Period*: October to March.

After subjecting the external temperatures into the ASHRAE 55 adaptive model, it was obtained the range 20-25 °C for temperate period. On the other hand, the range for cold period was set at: 18-23 °C.

With regard to occupation, initially it was considered to set the same family type for all the case studies. But then, it was reflected on the kind of families that live in a social housing. They used to exceed the estimated number of users (normally four persons). Therefore, as the goal is to improve the physical properties of the house, it was decided to take a standard value for the internal gains. The referenced value was obtained from the tool of Thermal Performance Certification of Buildings in Chile [12], where is indicated that to calculate the demand it is not necessary to specify the number of people who live in the dwelling. So, the option is an average of the sum of latent and sensible internal gains, which is stable as 160 Wh/m^2.

The geometry of the house was drawn with the information from the planes. Among other factors it was considered if the house was detached or not, because this will influence in the loss or gain of heat.

Another important input is the physical properties of the components. It was necessary to specify the elements that integrated each component of the building. The material properties were extracted from the information of the Chilean normative [13]. It was defined the conductivity (W/mk), the density (kg/m^3), the specific heat (J/kgK) and the thickness of each material.

To avoid major differences between the results from the different methodologies used, it was necessary to calibrate the model of dynamic simulation, i.e. it used the data in a complementary way, in order to approach reality. In the case of walls and windows, it was decided to use the values of thermal transmittance that have been given by the flowmetry test, since they reflect the reality of the current state. Another input used from the experimental diagnosis was the infiltration airflow rate. The infiltration of air can be very influential. In some homes the high infiltration can ensure the minimum level of ventilation recommended under hygienic perspectives, or otherwise, if the infiltration airflow rate is very low, it is necessary to design a ventilation system (either natural or mechanical).

The natural ventilation was defined as the need to ensure indoor air quality per area, not per people, because as it was explained it doesn’t identify the number of people who lives the case studies. There were set 2 ACH when the temperature inside the house exceeds 23 °C [14].

In order to determine the minimum of mechanical ventilation, it was used the ASHRAE as a reference. It requires an equivalent to 7.5 l/s per person, which is transformed to the unit of measurement required by DB (l/sm). Thus, in one case study this value was converted. The result was 0.89 l/sm, which allows concluding that the value used as the standard in all cases will be 1 l/sm², due to their approximation and because the Belgium normative uses it as well.

To know the current temperatures reached inside housing, it was necessary simulate without any heating or cooling system (free-running). The mechanical ventilation was considered lit throughout the day to ensure good indoor air quality. The house was considered occupied all day.

To have the knowledge about the energy demand of housing in terms of heating and cooling, the simulation state turns on the use of heating and cooling systems throughout the house and no longer free running. The fuel used is irrelevant, because at this stage it was necessary to know the demand and no the cost that it imply.

RESULTS

Free-running

To know the real house temperatures it was not included any type of heating and cooling system in the thermal simulations. The frequency variation of temperature results were divided into two graphics: one for the temperate period (Graph 1) and the other for cold period (Graph 2).

From 6 months considered in the temperate season, October is the month where houses have more hours outside the comfort range. This occurs because it is also the month that presents the lowest outside temperatures, and for this reason it is the same month that isn't overheated.

The four case studies show high percentage pass of the period in temperatures ranging between 14 and 20 ° C, i.e. users live most of the time out the range of comfort in the warmer months. The dwellings from Cabo Aroca and El Triángulo have the coldest inside temperature.

Overheating hours correspond to those who are over the temperature range. All case studies reveal a slight overheating, which mostly are between 25 and 26 ° C. Wood houses show greater warming (Cabo Aroca and El Triangulo). Inversely, Peñuelas II shows almost no temperatures exceeding the comfort range.

The solutions made with wood in the perimeter walls are not solid wood in any case. This kind of solution would provide a good insulation, but the real solution in the case studies is made based on framework wood with air between the structure and poor insulation. Furthermore, the solution of the wall is prone to the inadvertent holes (two meetings coating plates for example), where the air comes unintentionally, increasing the infiltration airflow rate.

In the frequency variation of temperature graph during the cold period, it is shown that most of the studied houses show a trend of temperature outside the comfort range established for the cold months (18 to 23 °C).

Of the four case studies examined, the dwelling of El Triángulo has more hours in the temperature comfort range during winter. Opposite of this is the P. Aylwin case, which represent the house with fewer hours in thermal comfort.

Unlike what happens in the temperate period, the houses built on wood (Cabo Aroca and El Triángulo) are those which have more hours within the comfort range during the cold period, this is compared to those brickwork built (Peñuelas II and P. Aylwin)that show even less than half of the hours within the temperature range in winter.

Although there are four housing interior temperatures between 18 and 23 ° C, being the most relevant ones under the range. Finally, 13 and 14 °C make the marked tendency.

With regard to overheating inside the houses, only the month of April caused worry, but it corresponded to the higher outdoor temperatures. The temperatures considered to generate overheating had almost no repercussions, because there are only up to 24 °C.

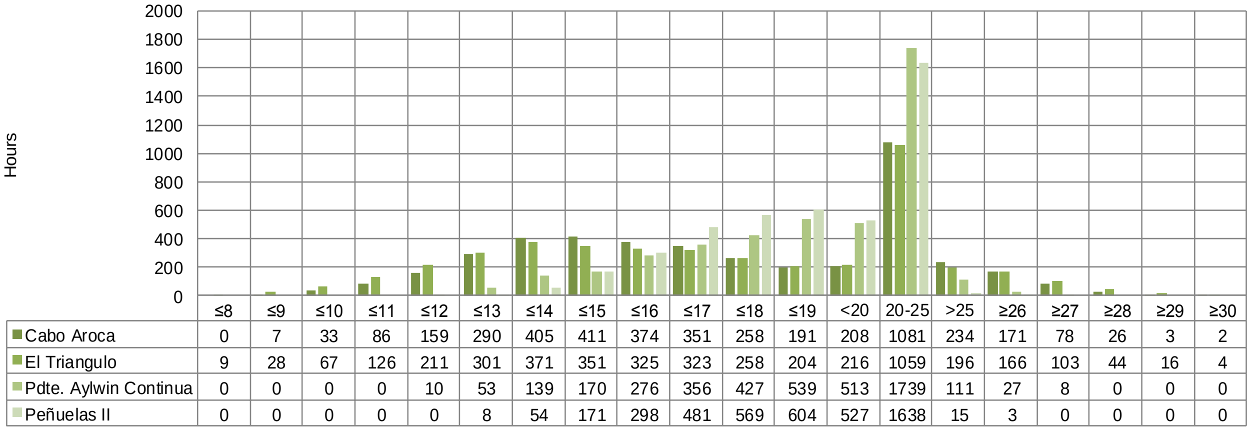
Heating energy demand

In the temperate period (from October to March) the demand is not significant, since the overheating is virtually non-existent. Because of this, is not necessary to use a cooling system.

Heating energy demand corresponds to the energy required to supply the difference between loss and gains of heat in cold periods.

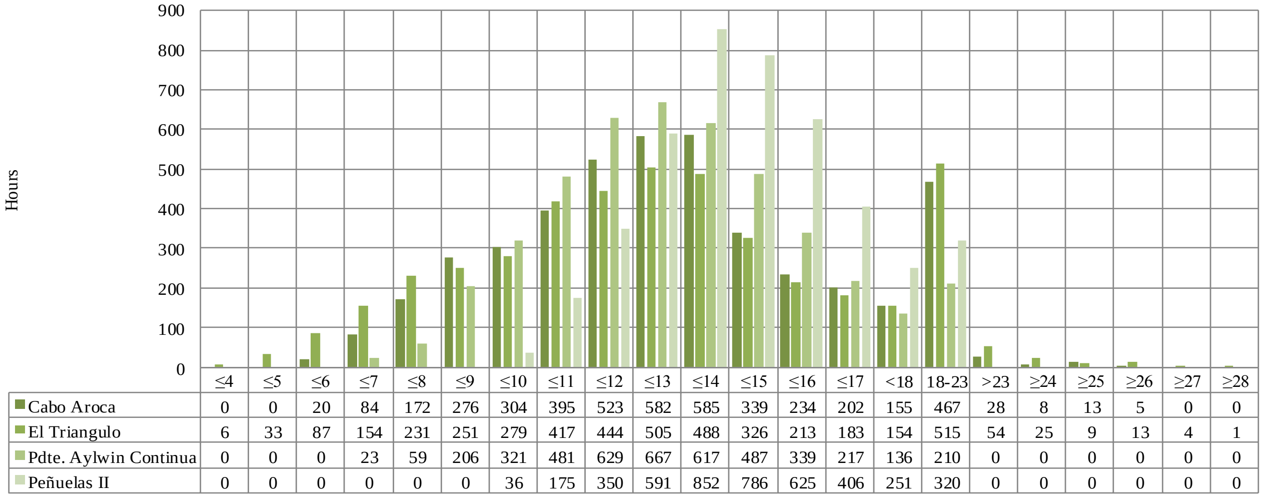
All dwellings showed different surfaces, so it was necessary to divide the annual demand (data from the Design Builder simulation) by usable area of each houses. In this way it is possible to obtain the annual demand per square meter. This measure unit will compare the case studies with each other (Table 4).

Cabo Aroca case is showing increased demand for heating energy per square meter. The following case is from El Triángulo. Both cases coincide to be made of wood and those are the houses that showed the greatest airflow infiltration rate.



	≤8	≤9	≤10	≤11	≤12	≤13	≤14	≤15	≤16	≤17	≤18	≤19	<20	20-25	>25	≥26	≥27	≥28	≥29	≥30
■ Cabo Aroca	0	7	33	86	159	290	405	411	374	351	258	191	208	1081	234	171	78	26	3	2
■ El Triangulo	9	28	67	126	211	301	371	351	325	323	258	204	216	1059	196	166	103	44	16	4
■ Pdte. Aylwin Continua	0	0	0	0	10	53	139	170	276	356	427	539	513	1739	111	27	8	0	0	0
■ Peñuelas II	0	0	0	0	0	8	54	171	298	481	569	604	527	1638	15	3	0	0	0	0

Graph 1: Frequency variation of Temperature of the Case Studies during Temperate Period.



	≤4	≤5	≤6	≤7	≤8	≤9	≤10	≤11	≤12	≤13	≤14	≤15	≤16	≤17	<18	18-23	>23	≥24	≥25	≥26	≥27	≥28
■ Cabo Aroca	0	0	20	84	172	276	304	395	523	582	585	339	234	202	155	467	28	8	13	5	0	0
■ El Triangulo	6	33	87	154	231	251	279	417	444	505	488	326	213	183	154	515	54	25	9	13	4	1
■ Pdte. Aylwin Continua	0	0	0	23	59	206	321	481	629	667	617	487	339	217	136	210	0	0	0	0	0	0
■ Peñuelas II	0	0	0	0	0	0	36	175	350	591	852	786	625	406	251	320	0	0	0	0	0	0

Graph 2: Frequency variation of Temperature of the Case Studies during Cold Period.

Table 4: Heating energy demand per case study.

	Cabo Aroca	P. Aylwin corner	P. Aylwin middle	Peñuelas II	El Triángulo
Annual Demand (kW/hm²)	184,4	163,4	126,3	124,5	165,3

The difference between the middle and the terminal house from P. Aylwin is very noticeable and it can only be because the shape of them, since the terminal dwelling has more surface area in contact with the outside, compared to the one with detached houses on both sides.

Another chilean research [15] state that the two-level and semi-detached house located in Conception (biggest city next to Hualpén), should demand 110 kWh/m²year. This value is lower than the ones obtained in the present study (between 157 and 165 kWh/m²year). The difference can be ascribed to various factors: the software used, the indoor temperature range to be in comfort, the use of real airflow infiltrations rate and, most importantly, the thermal quality of dwellings simulated (walls, ceilings, windows and floor).

Because of this different border conditions it is possible to have variant results in all the cases.

Other data obtained from DB is the results of the heat loss suffered by each element that form the envelope (Table 5). The results from this breakdown of elements responsible for energy losses showed that windows and ventilation (forced and natural one) are the main causative.

Table 5: Breakdown of elements responsible for energy losses

	1°	2°	3°	4°	5°	6°
Cabo Aroca	Walls	Infiltration	Ventilation	Window	Roof	Floor
El Triangulo	Walls	Ventilation	Infiltration	Window	Floor	Roof
Pdte. Aylwin middle	Ventilation	Walls	Windows	Floor	Infiltration	Roof
Pdte. Aylwin terminal	Walls	Ventilation	Infiltration	Window	Floor	Roof
Peñuelas II	Ventilation	Walls	Infiltration	Window	Roof	Floor

The houses with framework wood lose energy mainly through the perimeter walls. The case of Cabo Aroca, has the infiltration as second loss factor, because it was the house that showed increased infiltration during pressurization test. As fourth energy loss reason, this wood housing has the windows as responsible.

According to other research, windows mainly affect the energy loss. The reason that this element does not occupy the first places in terms of losses in this study, may be because in other studies air exchange per hour is not considered. Also the size of the windows in these social housing studied has little percentage compared to the wall.

Of the homes built in brick, the only one which has the walls as the first element of energy loss is the President Aylwin terminal case. It has the largest area of loss.

From the number of levels of housing, and the composition of floors and roofs, it can be concluded that one level houses lost more energy by the roof to the floor. It occurs an opposite situation in two level dwellings.

CONCLUSION

In the researches of the current state of housing there is not enough to simulate the energy efficiency in a validated software, since some data are considered such as ideal and no real (U-value, infiltration, etc.).

It is proposed to evaluate housing in an experimentally way, to obtain truthful data on the actual situation of the existing cases and then to take this data into the simulation, so it can be calibrated. Thus it can consider various factors that influence the performance houses.

The tightness of the envelope is a performance that has not been considered by the current chilean TR, and should be a requirement because their high influence when wanting to heat or ventilate the house. It can be drastic and determined that only eliminating infiltration may satisfy the requirements for energy saving. Having a multi-variant character, any improvement is influenced in the existing building. Improving the tightness of the envelope not only can save a lot of energy, but also can avoid producing putrefaction processes and fungi inside the house, so it is also an investment in the health of the users.

The idea of using a multi-factorial system in this research is to know which variables influence more or less the energy and environmental improvement, and how each of these can be improved having an impact on other parameters.

This research has implications on the architectural design, because it looks for established guidelines that can be used in future housing designs, which deliver higher habitability quality buildings. In terms of construction, this study looks for passive strategies to raise the comfort inside the dwellings and improve the physical properties of the envelope construction.

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