Revealing the Energy Efficiency of Housing in Chile

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ABSTRACT: Over recent years, Latin America has experienced continued development of vast residential areas with growing energy consumption of mostly imported and non-renewable fuels. Chile has been the first country in the region to set up programmes and regulations to improve environmental behaviour of dwellings, but there is a lack of detailed information on the energy performance of its housing stock. This paper presents the analysis and conditions for housing in the centre-south area of the country, in order to foster effective procedures to improve energy performance. Analysis is based on building statistics and the review of fifty actual homes, as well as energy simulation systems, with modelling and long-time monitoring of a dozen of these case studies. Some experiences of improved housing design and refurbishment were also examined. This research work identifies energy performance patterns and related architectural characteristics in housing in the area. It has managed to normalise specific aspects of residential energy simulation, such as climate, geometry, occupancy, materiality and equipment, demonstrating differences in comfort levels and building quality. The study exposes a novel strategy of review and improvement for residential areas, that reveals a conjunction between life expectations and construction quality, through analysis and appropriate actions, must be adapted to fit with local development.

KEYWORDS: Housing, Energy Simulation, Environmental Performance, Refurbishment, Chile.

INTRODUCTION

A large part of human activity takes place within the home, where construction and occupancy generates nearly a quarter of the growing global energy consumption. The Latin American continent has the highest urbanisation rate in the world, with sustained economic growth generating widespread housing development with poor environmental control and a high demand for imported, non-renewable fuels (IEA, 2012). Chile holds an exemplary position in the region, thanks to the country´s extensive support for dwelling and the recent implementation of energy improvement plans and standards for housing. However, there is a lack of detailed background information on home energy performance that could contribute to the design and use of environmental considerations (CNE, 2009). This paper presents a review of housing conditions in the centre-south area of Chile, based on general statistics and an exhaustive study of fifty actual homes, including building shape, materiality, occupancy and environmental monitoring as well as long-time review with energy simulations in twelve of the case studies. Regional experiences in housing design with high energy standards and refurbishment of existing homes were also examined in order to foster effective paths of action to analyse and improve housing energy performance.

1. HOUSING CONDITIONS IN THE CENTRE-SOUTH OF CHILE

The centre-south of Chile (the Maule, Bío-Bío and Araucanía regions) covers about 100,000 km^2 and stretches north-south from 34° 41’ to 39°37’ latitude and west-east from 71°15 to 71°30´ longitude between the Pacific coast and the Andes mountains. It has a temperate climate with different seasons, maximum summer temperatures between 10° to 25°, winter temperatures of 5° to 15°, relative humidity around 70% with mean rainfall levels close to 1,850 mm/year mostly in winter and mean radiation of 300 $cal/cm^2/day$. There are nearly four million inhabitants in the zone, mostly living in cities in the central valley and the main metropolitan area of Concepción on the coast. Homes are mainly located in low density urban periphery zones. They are mostly one or two-storey constructions of reinforced brickwork (15cm thick brick walls) and/or timber structure (2”x4” timber framed walls and ¾” timber board or sheet facing) with sloping roofs covered in fibre cement or metal sheeting (CCHC, 2011).

In 1977, environmental concern in the country led to the implementation of a climatic-housing zoning system with design recommendations and a register of construction materials used. In 2000, compulsory standards were introduced for the vertical elements (wall structures) used in housing and in 2007 for roof structures. Maximum thermal transmittance levels for the different building components in the region were fixed at 1.7

W/m^2/K for walls (previously values reached over 2.5 W/m^2/K) and 0.4 W/m^2/K for roofs (previously as much as 1.0 W/m^2/K or more) and suspended floors (which are uncommon); limits were also set for overall percentages of glazed areas. In recent years financial benefits have also been offered to install domestic solar heaters or more efficient electric heating equipment and to refurbish existing homes to improve their energy performance, although without setting specific technical regulations (Bardi y Rozas, 2010). A voluntary energy efficiency certification scheme is currently being applied to new housing units comparing different construction materials for the same design. These measures, although far inferior to equivalent European standards, are the precursors in Latin America and have influenced the development of some 200,000 new homes in the region over the last decade. However, it must be noted that over 80% of the existing housing stock in the area does not comply with these standards and will remain in use for several decades yet.

Figure1. Location of the region studied (left), map of urban areas (center), and view of residential zones (right).

1.1. Housing register

Fifty homes were surveyed in order to review the characteristics of housing in the region. Architecture and construction degree students were invited to submit data on their own homes (or those of nearby relatives) and in this way ensure involved and qualified observers. This group of homes was then compared with general residential building statistics to determine how representative they were of the population in general and to select a dozen case studies for more in-depth examination, including energy simulations and environmental improvement studies.

90% of the surveyed homes are located in urban areas (mostly around metropolitan Concepción) and 85% are single-family homes, which matches up with national and regional statistics (INE, 2002; Fissore, 2012), so the subsequent selection of case studies for more detailed review was made from these surveyed buildings. Almost half the houses surveyed are one storey and the remainders with two-storey, and similar distribution of detached constructions and semi-detached, in a variety of layouts. The volumes showed individual shape and wide variety in their design as is typical in the country and indeed in most of Latin America. Building materials are a mixture of brickwork and faced timber structure, both typical in the region.

Floor areas of the houses studied varied between 50m^2 and 250 m^2, close to twice that on official records, mostly due to the common practice of adding unregulated extensions at ground or roof level, in sites with area around 250m2. The study included both initial constructions and subsequent unregulated but similarly built extensions (in contrast to other countries where illegal extensions tend to differ from the original constructions). The buildings studied were of different ages, from 3 to 60 years old, with an overall average age of 25 years, in line with the age and renewal process of the country´s housing stock.

1.2. Occupancy and infrastructure

The houses studied had an average of 4.9 permanent occupants per unit, rather higher than the national and regional average of 3.6 inhabitants per home (INE, 2005), with an average age of 29.3, similar to statistics but with a predominance of young people between 20 and 25 years of age since the majority were older families, being homes of university students. On this account, the homes chosen for in-depth simulation, were selected from younger families (relatives of students) and average occupancy dropped to

3.8 per unit with a demographic age distribution more in line with general statistics while maintaining a similar size, materiality and shape diversity.

Annual family incomes varied between US$10,000 and US$60,000 per unit, with an average of about US$25,000, equivalent to the middle sector of the national population. Between 5% and 10% of income is spent on utility services, half of this on winter heating costs, which totals between US$250 and US$2,500 per unit annually.

All houses had fully-equipped electrical and sanitary installations with the vast array of domestic goods and appliances corresponding to national records (CDT, 2010) and typical of an emerging economy, including many energy efficiency accessories from national campaigns. They possessed a variety of heating systems (none had air-conditioning) and fuels with wood the most common choice due to its lower cost, but including paraffin, gas and electric heaters, mostly mobile units for occasional and combined use. According to the corresponding power conversion rates, energy consumption varies between 5,000 and 25,000 kWh per year, mostly dependent on family income levels, and not related with size of houses or users.

1.3. Environmental monitoring

Dry bulb temperature and relative humidity digital sensors were installed in the main living space of the fifty homes surveyed for one week. Also, in a dozen case studies, whole campaigns have been set up to monitor environmental performance in summer and winter periods, including the use of sensors in different parts of the house, both aerially and on inside and outside surfaces. Lighting and CO_2 levels are measured, as well as leakage (with blower door tests), thermographic images and local meteorological information are included. There has been some difficulty in managing and visualising data but the results have been consistent with regional estimates and other studies (Sarmiento and Hormazabal, 2003; Fissore, 2012). Indoor temperatures average about 18°, with a variation of ±2° and an average daily oscillation of ±3°, depending on outside temperatures, with relative indoor humidity averaging 75%. These figures are below those of conventional comfort levels and adaptive value calculations (which give a range of between 18° and 24°).

The thermal transmittance and solar radiation variables measured in the in-depth monitoring confirm both the values used in simulations and those set by housing standards. In contrast, the permeability values measured for indoor space proved considerably higher than both national standards and the values used in the simulations, reaching between 1 and 6 air renewals per hour. There is significant variation in these values for different rooms and according to the construction quality (and values are also high in some newly built houses). The thermograms also show significant differences in heat loss and comfort conditions according to the different construction types and interior spaces.

Figure 2. Monitoring of a House.

1.4 Comfort consultation

Normalised surveys (according to ISO 10551/95), interviews and observation were used to reach a qualitative notion of comfort and occupant behaviour. The assessments revealed that occupants were satisfied with their home environment; that is to say, the temperatures detected correspond to required comfort levels. However, those homes with lower temperatures and spending were less satisfied and the interviews revealed considerable variations. Differences were particularly marked within the homes (namely, differences between ground floor and first floor, or north and south-facing aspects), specific locations of heating equipment and timetable disparities between occupants. Thus, comfort levels were dependent on areas within the home and time-related aspects (during the day or year) and hence normalised assessment methods that review global aspects with specific consultations are inadequate to characterise such conditions.

In conversations and visual records other notable determining factors were the place of origin of occupants (when they come from rural or peripheral sectors), age and gender. However, the effects of these aspects are difficult to generalise since they are also influenced by size of family income (and hence spending), HVAC (heating and ventilation) and building quality. Therefore, income levels, which showed considerable disparities, also determine comfort expectations and change progressively with average family age. This situation fits with the expected conditions of an emerging economy with economic inequality and social mobility markedly more apparent with each new generation (AIM, 2008). For example, there is increasing functional disparity between occupants. Family groups are maintained but with increasing diversity in the activities of members of different ages and genders (such as studying or working from home). This can be seen in the low or single-person use of the social spaces in homes and high occupancy recorded in bedrooms as well as their different timetables. Therefore, comfort situations tend to differ from individual to individual (Frontczak, 2011). These personal tensions make conventional comfort measurement assessments as well as constructive solutions more difficult to achieve, demanding spatially and temporally differentiated analysis and resolution strategies.

2. ENERGY SIMULATIONS

There are currently a number of computing systems capable of analysing energy performance of buildings in line with standard methods (ISO 13790:2008-09 and ASHRAE 90.1), including programmes with a broad range of costs and capabilities and, more recently, web-based systems (EERE, 2012). We carried out extensive review of a dozen systems, including installation costs and basic testing, analysis of the same home with each system and interviews with expert users, as well as other studies (Crawley et al, 2008; Attia et al, 2009). A distinction was identified in the programmes between ease of use and range of capabilities. On the one hand more expensive and complex programmes used in larger-scale projects or by users with more expertise. On the other hand free, simpler systems that demonstrated rapid processing but with implementation difficulties and broad, limited results. These programmes can be used from time to time by professionals to obtain individual and preliminary estimates. The more advanced systems required greater effort at the processing stage but provided precise and diverse analyses. Then, they can be used by experienced users for more extensive studies in large-scale projects. Some intermediate programmes achieve good usability and technical attributes, and also provide information interchange. Following this review, a combined use of modelling software (Ecotect or Design Builder) was determined suitable with a complete calculation engine (EnergyPlus), Excel spreadsheets for analysis, and building information system (Revit) for design and documentation.

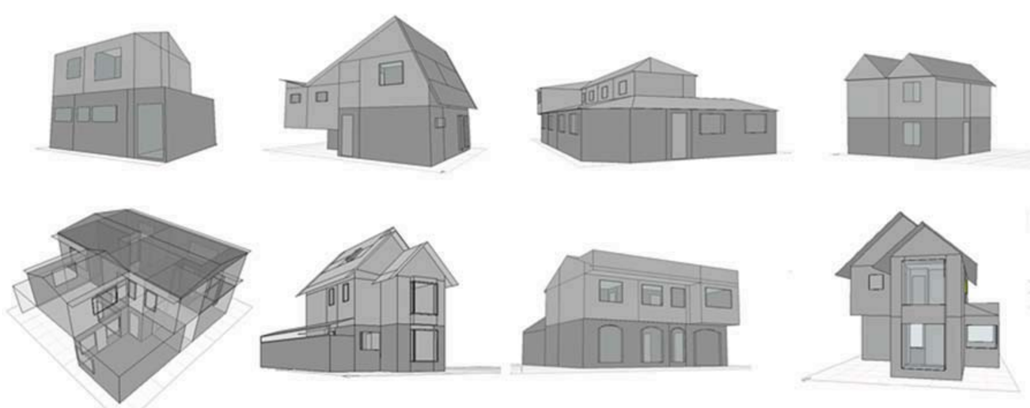

Figure 3. Some models of houses simulated.

2.1. Modelling of houses studied

Detailed studies of energy analysis of a dozen homes are being carried out by the same students living there or by their relatives. The weather information was established with IWEC database and local stations for verification. Geometric elaboration was regularized with initial outlines of measures on field that were then exported in dxf to generate thermal zones in the energy modelling software, controlling the superposition of planes and insertions of openings, as well as basic surroundings. Data consistency was verified due reiterated difficulties. The materials of each plane were defined in order to calculate thermal transmittance values for each building envelope according to the measurements taken. Calendars were drawn up for occupancy and for use of services according to the collected data. The process was normalized with a tutorial and group sessions.

2.2. Initial results

The modelling process took several hours for each case over a number of sessions, while the complete data was recorded and initial learning aspects and difficulties with the programmes were overcome. In the initial sequence of simulations information about climate, materiality, occupancy, heating and ventilation was verified generating variations of 5% to 10% in the results. Comparative simulations were then carried out between all the case studies (called the “base simulation”) with a comfort range according to adaptive value calculations of between 18° and 24° and 2 air renewals per hour, according to mean recorded values.

The energy demands in the base simulation of all the houses analysed were mostly for heating over the winter period with heat loss through vertical elements of the vertical building envelope. Global heat loss variables were between 3,000 and 30,000 kW/year and between 50 and 200 kWh/m^2 (for surface area), values consistent with estimates for the region and recorded consumption although distribution is somewhat different. Higher values occurred in the larger houses and highest losses per surface area were in the older homes in poor condition. All houses built over this decade have transmittance values of below 100 kWh/m^2 , due to incidence of recent thermal transmittance regulations and an overall improvement in building execution. Energy demands according to different zones within the home show significant disparity due to geometric and building configurations. Annual and daily fluctuations in indoor conditions respond to weather patterns so differences in location and solar orientation seems doesn’t have great influence in the demand.

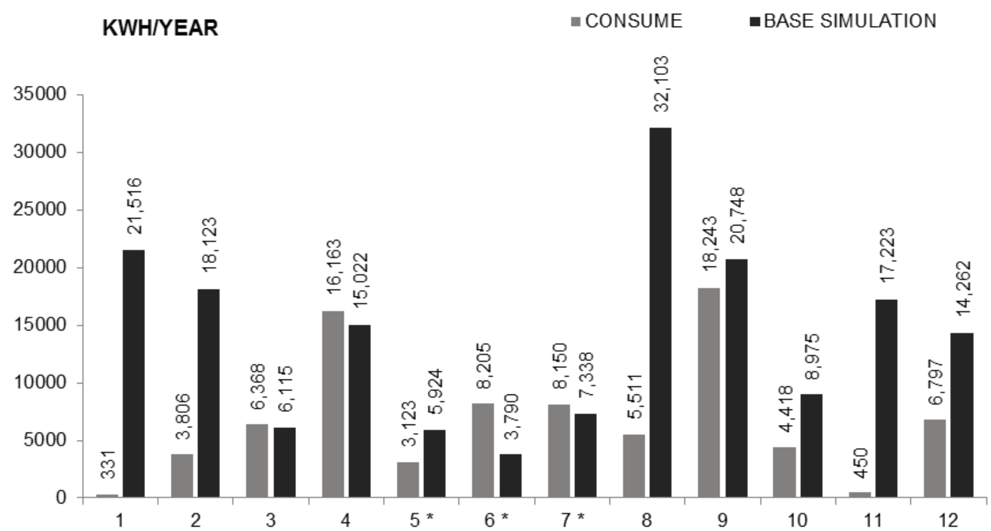

Figure 4. Results of energy consume by actual expenses and energy demand by base simulation.

2.3. Simulation adjustments

Several simulations were then carried out that were differentiated according to each case to achieve modelling equivalent to the real situation (called “adjustment simulations”), reviewing some details and modifying comfort and air renewal values according to individual recorded values since substantial differences were noted due to these factors. Results regarding demand were calibrated to recorded consumption levels, while also reviewing temperatures detected, infiltration test results and occupancy and heating calendars. Comparison with base simulations showed a similarity in some cases (in the more regular buildings) and considerable disparity in others (particularly lower income homes with low expenditure). Comfort levels rose in newer homes and by modifying certain variables in two or three further simulations values came much closer to real consumption levels. The oldest buildings in poor condition achieved much lower comfort levels (with a minimum of as low as 14°), thus increasing the number of building refurbishments. Therefore, infiltration and temperature levels present the greatest oscillations when seeking a reliable analysis of house building in the region.

2.4 Energy performance improvements

A number of design and construction measures have been suggested to improve environmental conditions in houses, in particular through some studies and experiences in the region (Trebilcock et al, 2003, Bustamante et al, 2005; Bustamante, 2009; Hatt, 2012, Carrasco and Kokogiannakis, 2012). These initiatives emphasize to increase thermal transmittance of the building envelope and implement servicing systems to recuperate heat or make use of solar absorption. Some advanced new-build houses with high energy standards in the region have proved the economic and technical feasibility of these possibilities, although without considering large-scale developments or demonstrating their real effectiveness once implemented. This research work seeks to provide specific energy performance improvements with massive possibilities, based on the analysis carried and verification of some proposals as following;

a) Geometric relationships of housing volume to reduce energy demand; comparative simulations were carried out on a single home with different shape configurations and orientations that demonstrate the incidence of volume compactness and contiguity in almost half of the energy demand and also lowers surface areas of outer walls and air volumes to be heated, pointing to the advantages of more densely built and terrace-type housing.
b) A procedure to design and evaluate insulating and sealing outer facing material, based on refurbishment experience carried on in existing homes. Energy simulations and budget calculations have demonstrated substantial improvements in comfort and energy efficiency with initial investment that can be recouped in only a few years. Monitoring occurred prior to and following installation and experts and inhabitants were consulted to verify performance, technical viability and social acceptance, with a number of alternative finishes used to incorporate diversity.
c) Parametric devices, as small-scale solar spaces added to some homes to capture passive solar radiation in thermically weak areas of the house. Sealed and insulating divisions in circulation spaces to separate different thermal zones within the home, in order to compensate and concentrate heating efficiency. Simulations and constructions are underway to test these devices to determine feasibility, performance and acceptability in homes.
d) A prefabricated housing design is being worked upon, with support from a local industry, including a number of extension and internal layout options, with highly insulating and heat absorbing perimeter components. Energy simulations, digital and material modelling is made to review behaviour, costs and appearance, as well as consults to industrial partners, agencies and users.

Any general use of these measures requires a reliable and integral assessment process of the design, building process, economic feasibility and occupant acceptance for a variety of case studies. Energy simulations adjusted to real living conditions lie at the heart of this process, interwoven with constructive modelling, budget analysis and financial and social validation processes.

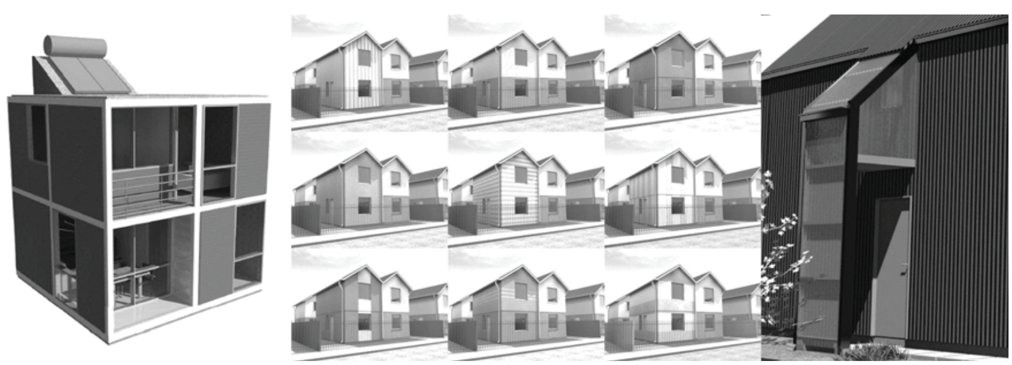

Figure 5. Prototype of energy efficiency-housing (left), alternatives of refurbishment with external insulation (center) and addition of solar space and door protection (right).

CONCLUSIONS

The review of living conditions in the centre-south of Chile reveals a predominance of diverse detached single-family homes with high and differentiated energy consume and reduced comfort levels, that are generally accepted by inhabitants although considerable disparities are detected within the different areas of each home. Energy simulation systems can be applied to these residential buildings and, with moderate effort in modelling selected case studies in a number of programmes, it is possible to estimate environmental improvements fairly accurately. Climate data can be regulated, as well as geometrical configuration, building conditions and occupancy. Simulations take into consideration both adaptive comfort and relatively high permeability. Significant variation remains concerning the diverse needs of individual occupants and existing cold bridges and air infiltration in buildings. These aspects are linked to individual expectations and building quality respectively. They seem to be influenced by family income levels and personal background, expressed in a preference for a variety of basically habitable spaces with individual internal divisions in terms of use patterns and comfort needs.

Energy efficiency improvements involve consolidating building volume and materials, sectoring and draught-sealing living spaces and incorporating passive solar heating or efficient heating systems. These measures can all be assessed with a combination of constructive modelling, energy simulation, budget studies and occupant consultation tools. These procedures would serve to determine the differential economic and social feasibility and promote effective refurbishment or new-build measures in either private projects or large-scale development programmes. This study exposes a novel strategy of review and improvement for residential areas, that reveals a conjunction between life expectations and construction quality, through analysis and appropriate actions, must be adapted to fit with local development

The next step for this research is the creation of an integrated system of analysis of energy performance, construction and economic aspects, with social visibility to demonstrate, in some cases, the use and effectiveness of energy efficiency improvements in the home.

ACKNOWLEDGEMENTS

Research Projects Fondecyt 1120165 and MEL-Conicyt 81100003

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