Incidence of Architectural Configuration on Energy Efficiency of Dwellings in the Centre-South of Chile

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ABSTRACT: After the 27F 2010 earthquake in central-south Chile a rethinking of the residential architecture was necessary. This was seen as an opportunity to review and improve energy efficiency of housing, both on its morphological-constructive aspects and on the methodological procedures for new development. Simulations of thermal performances indicate that the climatic conditions in the zone lead to winter heating demand that can be better fulfilled with a correct study of the morphology of the dwelling: shape factor, envelope, direct solar gain and orientation among others. From an urban distribution point of view, the prioritization of collective housing over single-family dwellings is a major factor in the final results. The integration of thermal mass and the improvements of the thermal envelope can contribute to a better construction standard that will help to reduce the energy consumption. During the research some housing prototypes have been designed, revealing a better integration to the local climatic and geographical conditions.

Keywords: Housing, energy efficiency, bioclimatic architecture

INTRODUCTION
In Chile there is a strong private housing production. This includes social housing with financial subsidies, which has allowed to lower the residential demands of the country, but with low land regulation and lack of urban infrastructure. The size finishes and densities are similar between social and upper-middle-class housing. Most of the re-construction programs after the earthquake of February 27th 2010 carried out the same housing configuration; this means single family houses in an extensive dwellings. This low density urban development, resulting in part from an economic growth, real state pressure and the obvious need to meet the housing demand of the poorest people has some weaknesses from an environmental point of view. In Chile, residential construction accounts for a quarter of total energy consumption [1], this means that a significant reduction in energy demand in this sector would have a significant economic and ecological impact throughout the country. If this is linked with the fact that the country lacks of natural resources of oil and natural gas and therefore imports much of its energy, the need to rethink the building market in relation to that request becomes evident. Chile faces the energy challenge by two parallel strategies, the first is, increasing the country's energy production capacity and the second, reducing the growing energy demand. In the residential area a thermal regulation is being implemented. The regulation is applied to 7 thermal zones and is scheduled in three phases; the first regulates the roofs since 2000 and the second rules walls, windows and ventilated floor thermal transmittance values since 2007. The third phase aims to be completed with energy certification. In that scenario, improving the housing envelope tops the list of requirements to limit energy demand. This paper presents initial progress in understanding the architectural and construction aspects that affect the energy performance of the housing stock by identifying particular morphological properties and material conditions. Performing a simple review of these characteristics related to architectonic configuration and some recommendations.

GEOGRAPHICAL AND POPULATION DISTRIBUTION
The central-south area of Chile includes the Maule, Bio-Bio and Araucanía regions. These were the most affected by the earthquake and tsunami of 27 February 2010, and identified as an area of opportunity to bring innovative processes to construction and housing rehabilitation since they are prioritized regions in the reconstruction plans [2]. Under current regulations these regions are divided in
4 heating zones [3] (defined by heating degree hours), with a strong horizontal differentiation in latitude, with the sole exception of the Andes (Figure 1). This division established by the regulations seems inadequate in relation to the regulation stated in NCH1079-2008 [4], which proposes major differences; the most relevant is a greater distinction between coastal, valley and mountain climate, combined with topographical differences in latitude, proximity to the sea and altitude.

The distribution of the population in the study region [5, 6] reveals both the tendency to live in cities and the distribution of housing, with an overwhelming majority of single-family buildings. By region, Maule has 15 cities, which account for 57.9% of the total population of the region and which account for 56.8% of homes. The cities with the largest number of inhabitants are located in the centre of the region with a very similar climate. The largest city located in a different climate is Constitution, located at the coast.

The Bio Bio region has 35 cities which account for 77.1% of the total regional population with 74.4% of housing. The area that has the largest number of population and housing is “el gran Concepción” which is located along the coast and includes Concepción, Penco Talcahuano with 887,381 inhabitants. Along the coast and further south, Lebu city is another density pole, in this case geographic conditions are more exposed to the coast. In the center valley, the highest population densities are located in Chillán and Los Angeles.

The Araucania region has 20 cities which account for 59.8% of the total regional population and 56.8% of housing in the region. The city with the largest number of inhabitants is Temuco, located in the central valley area. The remaining villages are more disperse. The coastal area, in statistical terms, is very sparsely populated. In the Andes lie the two most populated towns around the axis of the southern Andes; Pucon-Vilarrica system with highly variable densities due to the seasonality of their occupation.

Regarding the thermal zoning, according to current regulations, most of the population is concentrated in Zone 4 and to a lesser extent, in the 5, with Zone 3 (north of Maule) and mountain range with least population. Therefore, the strategic actions to improve residential building should focus primarily on single-family homes in the towns of the zone 4, and to a lesser extent, on the 5, since a reduction in energy consumption in this area would have a multiplier effect and a strong impact because of the high population density.

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**CLIMATIC ANALYSIS**

To establish more specific recommendations to optimize architectural design, Givoni bioclimatic Chart [7] has been used at the places specified above. This analysis considers more parameters than the ones that define the normative and as a result they suggest more strategies
than improvements of the envelope. In the charts the same standard developed in similar research in other latitudes has been used[8]. Although the Chilean legislation provides lower standards of comfort (15°C for estimating the heating degree days) we considered using a standard of comfort most universally accepted as a measure of comparison, and considering that the gradual increase in the quality of life and welfare will suggest an increase in comfort standards. The study was conducted using weather data obtained from observatories in the areas studied, with average maximum and minimum temperatures and humidity levels for each month.

Maule Region:
This region has three distinct climate areas. Most of the population is distributed in the coastal zone (minority) and central (majority), with the Andes practically with a testimonial occupation. In the case of the central zone, the conditions of comfort could be achieved basically by capture and accumulation of solar radiation into thermal mass. Only the most extreme values need winter heating an external support. In summer some overheating may occur, which could be solved by ventilation and void protection. In the coastal zone, given the mitigation effect of the sea, even such extreme conditions may be assumed, as long as the moisture inside of buildings is mitigated.

Bio-Bio Region:
The existence of three distinct climatic zones It is here also noted, although in this case, the coast is much more populated than the central, and very concentrated. The Andean region has practically no population. In the case of the central zone comfort conditions could be achieved primarily through capture and accumulation of solar radiation on thermal mass, taking care of specific overheating in summer. Protecting openings, avoiding direct solar gains and introducing ventilation could be needed at extremely high and unusual temperatures. The minimum values during winter need supportive active heating. In the coastal zone, mitigating effect of the sea is considered only in the summer months because during the winter months some heating supplementation is necessary (Figure 2.)

Araucania region:
The region has three distinct climatical areas, although the population is clustered mainly in the central valley area. The mountainous conurbation Pucón-Villarrica is the second most populated section. In both areas the climate is quite extreme, with greater temperature oscillations in Temuco, which also has moisture in winter. In the central area, much of the cold claims can be resolved with direct solar gains.

In both cases there is loss of comfort due to cold, extreme and longer winter in the mountainous area derivates in heating requirements throughout the year. From the analysis performed on the areas of greatest population (and considered significant by covering a replicable area) some considerations are taken:

Three major climatic conditions linked to specific geographical areas are considered: coastal, central and mountain. Latitude influences the response in terms of more extreme cold conditions southward and towards the west, approaching to the Andes. In all situations, the problem always implies comfort needs of heat, and in many cases protecting or decreasing moisture as general recommendations for the entire region in study we can state:

- No cooling problems are expected, except some generated from deficient architectural design. It would be enough to protect the openings of radiation and avoid accumulating it, or to delay the accumulation about 8 hours to get good comfort conditions in summer, especially in central areas.
- Problems arising from the heat demand can be solved, for most time of year, using direct solar gains and thermal mass accumulation. Except for mountain areas, where active heating support is needed throughout the year. In the remaining climatic zones specific active heating support would be enough between May and September, which could be in low temperature, if they were supported by passive heating.
- A heating system is required for supporting the lower peak temperatures in almost all situations. The design and specification of heating system are considered relevant when focusing on a reduction of energy usage. It is recommended to study the most appropriate heat system and sizing in an integrated design process considering energy costs, maintenance and use.
RESIDENTIAL MARKET
Most of the existing dwellings in the study region correspond to detached and semi-detached houses with one or two floors, with percentages around 90% of the housing area in the three regions. The current tendency in reconstruction is to build at low density in one or two floors, over collective housing (Figure 3).

Figure 3: Detached houses at a reconstructed neighbourhood in Concepción

Typological Studies were performed to determine theoretically the relationship between density, grouping and energy demand. In general it is determined that, at lower density, the energy demand per housing unit increases, due to bigger transmission loss through the envelope. If we add to this the environmental costs in land use, the increase in supply networks, transport costs due to increased distances (which leads to an increased use of private transport) gives a bleak picture concerning the overall sustainability in territory.

Regarding to morphological properties, there is no legislation or regulation about the orientation of buildings in Chile. Form factor, sun screening, percentage of obstructions and other defining characteristics when positioned in a more efficient way are determinant to minimize losses and maximize energy gains. The distribution of urbanization and apartment blocks seem to come forth by the need to maximize the profitability of the land, that other issues intrinsic to the practice of architecture. Data of building permits of the municipality of Concepción [9] shows that 41.1% of homes were built with brick walls without any insulation and 25.8% were built in reinforced concrete (mainly high-rise buildings). Other types of walls were combined with woodblocks (8.7%), wood (12.4%) and cement blocks (5.8%). The most common construction system in Chile is confined masonry, with concrete slab. In two-storey houses, the second floor is usually done with a wooden structure.

Without proper data about the isolation and woodwork, one can conclude that both have been done with the minimum isolation required by the regulations in force. Data about the type of construction does not distinguish the position of the insulation within the wall or the composition of floors and roofs, but the most common practice is to layer the thermal insulation at the interior of renewed construction, and the placement of a thermal mortar about 1cm thick outside a new construction. For wooden structure the isolation goes between the wooden partitions.

MORPHOLOGIC ANALYSIS
There have been some schematic simulations [10], to comparatively review the thermal behavior of low density housing. This simulations need to be verified, but they serve as a general guide. The starter model was a standard dwelling of 90m² on two floors, located in Concepcion, with a traditional layout, gable roof and a front window ratio of 30% facing north and 20% south. East and west facades are despised because many of the homes visited had openings in the lateral walls to allow housing attachment. This choice also allows simulating detached; semi detached and terraced houses without changing the parameters of comparison.

Considering a construction according to transmittance values proposed by the Thermal Regulations for Zone 4. We used a square or rectangular of 6.7 m. Variations on the constructive parameters were modeled to find out improvement produced by increasing the transmittance values in walls and floors, window type, and presence of thermal mass. To do this, we used an improved house according to parameters of the Spanish Technical Code, using intermediate values for zones C and D. As thermal mass only the first 10cm were considered in contact with the inner environment. All cases were studied for a north-south position with respect to the axis of the facade.

Regarding the method of analysis, it can be inferred that the strict application of the standard obtains a poor energy performance. Without considering the reliability assigned to the used program, less accurate than others [11], it should be noted that the deviation is constant. In any case, although the values obtained cannot be taken as absolute, are indicative and may be related to the starting model.

Considering the envelope, savings of up to 44% by using terraced housing and 23% referring to a semi-detached home can be achieved. These figures only consider the grouping as a factor. The next factor is the improvement of the envelope, considering greater
isolation, without increasing the thermal mass, you get a decrease in consumption of around 39% although in this case, improvements are inversely proportional to grouping. In the case of terraced houses, this difference is reduced to 33%. Improving the thermal mass affects performance by approximately 50% in housing that meets the requirements. This finding is of key importance, since it is something not included in the standard. At the same time, wall transmittance values are not the same answers depending on where the isolation and the thermal mass of the building is located.

The last analyzed improvement is solar gain, although they are significant, one must first have thermal mass inside the building. The simulations show that the absence of thermal mass, (with increased solar gain) only leads to major differences in the temperature range inside, but no cumulative earnings. Incorporating thermal mass, and increasing the window surface, leads to variable but significant improvements. Isolated houses go up to a 63%, whereas grouped housing expand to 62% and to 72%, depending on whether it is semi detached (less difference) or terraced (more efficient).

More profits could be achieved considering catchment by skylights, an option very advantageous and feasible in the typologies of dwelling in study, although it should be noted that the radiation received on deck in winter, between 57° and 90° tilt, represents only 20% of the total radiation received between 27° and 57° tilt [12], so the skylights should be oriented and tilted adequately enough to receive radiation and effectively.

**CONCLUSION**

Dwellings in central-southern Chile are characterized by similar morphology, consisting mostly of single family houses about 60 to 140 m2, executed in reinforced masonry in the ground level and wood partition in the first floor and roof. The studied zone has a temperate climate whose energy requirements are substantially heating, where housing has a share of 22% of national energy consumption. The earthquake of February 27, 2010 affected a significant amount of homes that are being rebuilt in similar conditions to those existing. This means applying a constructive regulation that considers an inaccurate thermal zoning and restricts only the transmittance values of the envelope.

The contrast stated in figure 4 warns us about the incidence of grouping and envelope condition. Shape factor, grouping, position towards the sun, materiality of the envelope and amount of openings altogether condition the thermal performance of the buildings. From this analysis one can derive some recommendations for design and construction. Promoting more continuous volumes, as well as increasing the transmittance values, and positioning the insulation and thermal mass in a logical order.

Moreover, it would be a good improvement to introduce regulations regarding to sunlight, promoting a sunlight ratio (about 4 hours) in a certain percentage of catchment areas related to the surface and including a greater control of the transmittance in glasses.

A further increase of the capture windows area to north is suggested, at least up to 20% of floor area. From this percentage on, it is necessary to protect the openings facing the solar radiation in non-winter months. Solar gains can be achieved by the correct orientation of the building, its proper distribution and compactness, and capture areas, mainly as the relationship between incident radiation surface, floor space, storage capacity (thermal inertia) and transmission loss (isolation). Radiation could be optimized using the roof for capture, given the inclination, very penalized in winter from 57° tilt on.

The distribution of thermal mass and insulation is critical in achieving the cumulative solar gains. Under conditions of heat capture, as is the case, it seems...
advisable to put the isolation to the outside and leave thermal mass to the inside and to protect the openings to prevent overheating. Harmonize design and construction measures with performance analysis can contribute to an effective improvement. This review about energy efficiency of homes in the south-central Chile reveals specific requirements and actions that can be implemented at the existing housing stock and reconstruction programs either way. Grouping conditions, solar gain and materiality of the vertical envelope are altogether significant to achieve substantial improvement of environmental quality in homes.

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