Determination of Dwelling Typologies in Chile to Define Energy Efficiency Programmes

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Abstract. The Ministry of Housing and Urbanism of Chile (MINVU) has led the implementation of thermal conditioning requirements in dwellings (2000, 2007) as well as the Dwellings Energy Rating System (2012). To design improvements to both programmes, MINVU required a statistical analysis identifying the statistical distribution of the different parameters that influence the energy demand of the dwellings, as well as typologies and their distribution, both at the national level as well as that of the 9 thermal zones. A series of statistical analyses was developed for this purpose; mainly a Conglomerates Analysis, using specifically the hierarchic agglomerative method. This method was applied to detached dwellings, Semi-detached or Terraced dwellings and Apartment segments. So as to obtain more stable frequencies, as well as estimate standard deviations and confidence intervals, 200 random samples were obtained for each segment. The main result was the definition of 13 dwelling typologies in Chile, their respective distribution at the national and thermal zones levels, as well as the representation of the parameters that compose these typologies and influence energy demands. Finally, an analysis was carried out, based on secondary images of dwellings representing their respective typologies; this allowed complementing and correcting the typologies’ definition where it should be necessary.

A second study is being carried out at the time of closing this document –using those results- this shall allow to establish the energy demand of dwellings built in Chile before 2018, by typology, thermal zone and thermal regulations stage, so that Minvu may quantitatively define the energy demand baseline, consolidate measurement metrics, and refine long-term improvement objectives.

1. Introduction
The Ministry of Housing and Urbanism has led important steps for the building quality improvement to be applied to dwellings in Chile; among these, the Thermal Regulations (RT), has a very important role as it sets a minimum housing thermal comfort standard and reduces the risk of construction pathologies. The RT addresses the thermal energy transfer behaviour of the main components of the envelope: this has a direct impact on the improvement of the overall energy performance of the dwellings.

To precisely identify the improvements achieved thanks to the Thermal Regulations and to continue progressing in this field, the Ministry of Housing and Urbanism (Minvu), together with

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an external working group of statistics, energy efficiency, building and data processing specialists, has carried out a study to characterise the Chilean dwellings stock in function of the main parameters that impact its energy demand. The main result of this study was the identification -based on statistical procedures- of 13 typologies or dwellings archetypes grounded on nine main parameters which influence their thermal energy needs. This work is part of a larger study that is being developed by Minvu, to be published during 2020; it shall define the geometry and technical specifications of those typologies, together with the energy demand of the dwellings stock built in Chile up to 2018.

2. Methodology

2.1. Variables
On the basis of the experience gathered during the operation of the first version of the Housing Energy Rating developed by Minvu and the Ministry of Energy (in operation since 2012), 6 variables of initial interest were defined (V1 to V6, show in the list below). Since it was necessary to characterise each variable in each thermal zone of the Dwellings Energy Rating system, the thermal zone was considered as dependent variable (V0) and the behaviour of the other independent variables (initially V1 to V6) is analysed in function of it.

During the development of the study and taking into consideration the dwelling typologies defined in prior studies and their influence on energy demand, it was decided to address two additional independent variables (V7 and V8). The variables employed are listed below:

V0. Thermal zone (A, B, C, D, E, F, G, H, 1).
V1. Window frame types (Metal with and without thermal bridge brake or RPT, PVC and Wood).
V2. Window-to-Wall Ratio or FVM
V3. Type of grouping (Detached, Semi-detached or Terraced and Apartment).
V4. Construction year (three sets of years, in function of the Thermal Regulations in force).
V5. Predominant wall material (Heavy, Intermediate and Lightweight).
V6. Built area (m2).
V7. Number of storeys.
V8. Solar Accessibility Factor of FA (Solar radiation that can be accessed by the windows).

2.2. Collection, clearing and re-coding of data
First, it was necessary to study and analyse the datasets of the different primary sources. The table below shows the sources consulted and numbers of cases.

| Data Source                              | Scope                     | Cases        |
|------------------------------------------|---------------------------|--------------|
| Energy Qualification of the Dwellings (CEV) | 2009-2017                | 37,724       |
| Internal Revenue Service (SII)          | Historic (accumulative)   | 9,204,508    |
| Single Dwelling Statistics Form (FUE INE) | PE between1990-2001       | 244,687      |
| Single Dwelling Statistics Form (FUE INE) | PE between2002-2017       | 443,040      |
| 2017 Census                              | Total                     | 5,484,605    |
| Casen 2017                               | Representative sample     | 264,284      |

Source: Own compilation based on [1] and [2]

Once the primary datasets were available, an ETL process (Extract, Transform, and Load) was carried out, and the availability of the variables studied in the different data sources was verified. As a first result, it was ascertained that there was not a single source that had simultaneously all the variables studied, and that it was not possible to blend the datasets, since they did not share a common dwellings identifier.
Table 2. Variables studied in the available datasets

| Variable                   | Variable type | SII | FUE | INE | CEV |
|----------------------------|---------------|-----|-----|-----|-----|
| V0. Thermal zone (dependent variable) | Non-numerical | yes | yes | yes |     |
| V1. Type of window frames  | Non-numerical |     |     | yes | yes |
| V2. Windows in respect to the envelope | Numerical     |     |   - |     | yes |
| V3. Type of grouping       | Non-numerical |     |     | yes | yes |
| V4. Year built             | Numerical     | yes |     | yes |   * |
| V5. Predominant material   | Non-numerical |     | yes |     | yes |
| V6. Surface built          | Numerical     |     | yes |     | yes |
| V7. Number of storeys      | Numerical     |     | yes |     | yes |
| V8. Accessibility Factor   | Numerical     |     |     |     | yes |

* Although the CEV source shows the years as a variable, it is a relatively recent and does not allow obtaining the results required for this study as regards this variable.

Source: Prepared by the authors

Because it was appropriate to analyse the variables as an ensemble, in order to generate representative dwellings typologies in function of the interaction of multiple variables, the dataset of the Single Dwelling Statistics Form (FUE INE) was employed, as it contained the greater number of variables under study, and is a representative database rather than the CEV which shows very recent data.

To incorporate in the typologies the variables not considered in the INE source [FVM (V2) and FA (V8)], the CEV dataset was considered as reference, on the basis of the averages observed for each segment and wall materials. Finally, it must be pointed out that two additional variables were included: the Number of Storeys and the Accessibility Factor so that it would be comparable to the definition of typologies that the Minvu uses, based on prior studies. It must be pointed out that the variables studied are Numeric as well as Non-numeric or categorical. The numeric variables have a number of values, whether accountable or infinite, between two any values, while the non-numeric or categorical variables have a finite number of different categories or groups. The numeric variables allow the application of a wider range of statistics calculations

Finally, it was necessary to adopt criteria for the coding of some fields that did require it, so as to be able to assimilate them to the codes defined for the studied variables. This procedure was necessary for most of the variables.

2.3. Sampling

A probabilistic sample was obtained, size 10,000, employing the stratified random sampling method with climate Zones (V0) as strata. The quantity in each Zone was defined in a manner approximately proportional to the size of the stratum, rounding up to the hundreds. The sampling sizes to be used in the study were determined by breaking down the available observations for each thermal zone and distributing them for each zone and years period mentioned before. In this sample, a large number of cases referred to housing developments having a single record for the whole development, setting out the total surface and the frequency of matching dwellings. Therefore, the surface area was divided by the respective number of dwellings, thus obtaining the single dwelling area. The sample was expanded later on, repeating each dwelling the number of times corresponding to the respective frequency. Using this procedure, the new quantity increased to 41,505 dwellings. The sample was then refined, eliminating cases that showed errors in data collection.

For the definition of typologies analysis, the sample was separated into three groups or segments, according to the value of the Grouping variable (V3): Detached dwelling, Semi-detached or Terraced dwellings and Apartment. A random sample of each group was obtained by systematic sampling all of 1,000 sizes. The procedure was repeated later on, in order to identify the defined confidence level, with 600 samples of the same size, delivering practically the same conglomerates results. This last step is a resampling procedure, which is an adaptation
of the Bootstrap method to the conditions of this study [3]. Resampling is employed whenever something must be estimated, and it cannot be done using a single sample, so many samples as required, opting to obtain sub-samples of the same original sample.

2.4. Analysis of conglomerates

An Analysis of Conglomerates was applied to determine the typologies. Other options were a discriminating analysis -but this works with numeric variables only- and the CART method (Classification and Regression Trees), but this only works with small samples [4]. The analysis of conglomerates consists in finding groups (or clusters) of observations. A distance between objects must be defined. There are several ways to define distances, all for numeric data, except one that is useful for categorical data (non-numeric), and which could be applied to this study. The distance among conglomerates was defined on the basis of this distance. Among the conglomerates analyses there is a hierarchical agglomerative method, so as to form clusters, a hierarchical divisive (inverse) method and non-hierarchical methods, the most popular is that of the k-median. The hierarchical agglomerative method was employed in this study.

The hierarchical agglomerative method starts by calculating a matrix of distances between cases. The sample size is n; the distances matrix dimension is nxn, symmetric, with zeroes on the diagonal (the distances between each case and itself). A measure of the distance between conglomerates is also defined. Initially, each case is a conglomerate. In each following stage, the conglomerates being at lesser distances are joined. Finally, it is found that all the cases form a single conglomerate. The result is a diagram that shows the whole conglomeration process, from the n initial conglomerates up to the single final conglomerate. Then the user chooses the number of conglomerates he believes most convenient, together with its corresponding grouping diagram. This diagram is usually represented by a graph called dendogram: in the horizontal axis are shown all the cases, suitably ordered; the vertical axis shows the joining and indicates at what distances they took place. One of is characteristics is that the distances increase. It is usual to choose the conglomeration where the union distance shows a marked increase in respect to the former, as is shown in figure 1.

![Figure 1. Dendogram example](image)

Some relevant methodology issues of the hierarchical agglomerative method employed in this study are detailed below.
2.4.1. Distances among cases.
There are different forms of measuring the distances among cases. The Euclidean or Pythagorean distance was employed in this study: the distance between two cases is the square root of the sum of the squares of the differences of the components of the vectors corresponding to the two cases. The Euclidean distance can only be calculated for numeric scale variables. In this study all variables are either categorical or, being numeric such as 'Surface area', have been categorized. The solution was to introduce Dummy variables.

2.4.2. Distances between conglomerates
The Ward or distance method was used: it is one of the most commonly employed [4]. It tends to maximise homogeneity within the conglomerates. This delivers very compact groups of similar size and is generally more discriminative in the determination of the grouping levels. The Ward method assumes that the loss of information which takes place when joining two conglomerates into one can be measured by the sum of all the squares of the deviations between each case and the medians vector or centroid of the resulting conglomerate (the Euclidean distance).

2.4.3. Simultaneous Confidence intervals.
In this instance, the point was the estimation of the full set of each of the variables, considering each of the climate zones, therefore the simultaneous confidence coefficient for the Zones was taken into account, and not each one individually. For this reason the simultaneous confidence coefficient was reduced, using the Bonferroni method [4], which establishes that if there are k confidence intervals, each with a C confidence coefficient, the confidence that all should simultaneously contain their parameters results from 100-(100-C)k, which is 100-(100-99)x9=91%.

3. Application
In this study the dwellings are the cases and the resulting conglomerates are the groups that define the typologies. As mentioned, the work was based on three dwelling segments: Detached, Semi-detached or Terraced and Apartment, and a total of 8 Variables, of these, six are part of the conglomerates analysis as they come from the same data source (FUE INE), and the other two variables: FVM (V2) and FA (V8) were incorporated later on from the CEV database (see section 4.2). So as to obtain more stable frequencies and be able to estimate the standard deviations and confidence intervals, 200 random samples, size 1.000 each (sub-samples of the original sample) were obtained in each stratum (600 in total), starting from the original sample of the corresponding stratum; the procedure was repeated with each of them as explained in section 2.3 Sampling. The dendograms of each of the 200 samples of 1000 dwellings for each segment showed that the adequate numbers of conglomerates were: 5 for the detached dwellings segment; 4 for the semi-detached or terraced dwelling segment, and 4 for the Apartment segment, as shown in figure 2. The lower section of the graph is eliminated, because, given the large number of cases (1000), it would only show as a black spot.

![Figure 2. Dendogram Detached dwelling](image)

The distribution of cases for each variable, code of the variable, standard deviation and confidence intervals were obtained for each conglomerate. The results are discussed below.
4. Typologies Proposal

4.1. Main variables

A total of 13 typologies is proposed, corresponding to the different groups or conglomerates generated from the analysis explained in the above section. It is important to note that in the analysis there are typologies showing variables with more than one category, and even without a preponderant category. This situation mainly occurs for the “Wall Material” (Table 3) and “Surface area” (Table 4) variables.

Table 3. Representativeness of the Wall Material variable for each Typology, in %

| Segment          | Typology | Wall material |
|------------------|----------|---------------|
|                  |          | L  | L-I | L-P | I-L | I  | I-P | P-L | P-I | P |
| Detached dwelling| 1 or CA1 | 2  | 0   | 0   | 3   | 90 | 0   | 0   | 0   | 4 |
|                  | 2 or CA2 | 83 | 0   | 0   | 3   | 12 | 0   | 0   | 0   | 2 |
|                  | 3 or CA3 | 17 | 0   | 0   | 33  | 39 | 1   | 0   | 0   | 10|
|                  | 4 or CA4 | 27 | 0   | 0   | 56  | 11 | 1   | 0   | 0   | 6 |
|                  | 5 or CA5 | 94 | 0   | 0   | 1   | 3  | 0   | 0   | 0   | 2 |
| Semi-detached or | 6 or CPC1| 44 | 2   | 0   | 50  | 1  | 0   | 0   | 0   | 3 |
| Terraced dwelling| 7 or CPC2| 0  | 0   | 0   | 0   | 100| 0   | 0   | 0   | 0 |
|                  | 8 or CPC3| 2  | 0   | 0   | 98  | 0  | 0   | 0   | 0   | 0 |
|                  | 9 or CPC4| 58 | 2   | 0   | 33  | 4  | 0   | 0   | 0   | 3 |
| Apartment        | 10 or D1 | 0  | 0   | 0   | 0   | 0  | 9   | 0   | 0   | 91|
|                  | 11 or D2 | 0  | 0   | 0   | 0   | 0  | 0   | 0   | 0   | 100|
|                  | 12 or D3 | 0  | 0   | 0   | 9   | 0  | 0   | 0   | 0   | 91|
|                  | 13 or D4 | 0  | 0   | 0   | 9   | 0  | 0   | 0   | 0   | 91|

Note: Light (L), Light-Intermediate (L-I), Light-Heavy (L-P), Intermediate-Light (I-L), Intermediate (I), Intermediate-Heavy (I-P), Heavy-Light (P-L), Heavy-Intermediate (P-I), Heavy (P).

Source: Prepared by the authors

Table 4. Representativeness of the variables Windows Frames, Number of Storeys and Surface area, for each typology in %

| Segment          | Typology | Window frames | Number of storeys | Surface area [m²] |
|------------------|----------|---------------|-------------------|-------------------|
|                  |          | Metal | Wood | PVC | Other | 1 | 2 | 3 | <35 | >35 to 50 | >50 to 70 | >70 to 100 | >100 to 140 | >140 |
| Detached dwelling| 1 or CA1 | 93   | 3    | 3   | 0    | 99 | 1  | 0 | 15 | 26 | 25 | 13 | 9 | 12 |
|                  | 2 or CA2 | 6    | 42   | 51  | 1    | 86 | 14 | 0 | 18 | 28 | 22 | 12 | 9 | 11 |
|                  | 3 or CA3 | 94   | 2    | 4   | 0    | 3  | 96 | 1 | 10 | 42 | 19 | 8  | 7 | 14 |
|                  | 4 or CA4 | 5    | 3    | 92  | 0    | 2  | 98 | 0 | 21 | 28 | 18 | 5  | 12 | 16 |
|                  | 5 or CA5 | 90   | 5    | 5   | 0    | 98 | 2  | 0 | 18 | 22 | 16 | 11 | 17 | 16 |
| Semi-detached or | 6 or CPC1| 81   | 1    | 17  | 0    | 15 | 83 | 2 | 17 | 21 | 26 | 11 | 15 | 11 |
| Terraced dwelling| 7 or CPC2| 100  | 0    | 0   | 0    | 0  | 98 | 2 | 24 | 13 | 15 | 14 | 13 | 22 |
|                  | 8 or CPC3| 100  | 0    | 0   | 0    | 81 | 0  | 19| 18 | 22 | 29 | 14 | 9  | 9  |
|                  | 9 or CPC4| 44   | 19   | 37  | 1    | 32 | 63 | 5 | 15 | 27 | 27 | 9  | 12 | 11 |
| Apartment        | 10 or D1 | 100  | 0    | 0   | 0    | 100| 0  | 0 | 24 | 16 | 0  | 30 | 30 |
|                  | 11 or D2 | 100  | 0    | 0   | 0    | 100| 0  | 0 | 20 | 19 | 30 | 15 | 15 |
|                  | 12 or D3 | 100  | 0    | 0   | 0    | 100| 0  | 0 | 0  | 0  | 100| 0  | 0  | 0  |
|                  | 13 or D4 | 100  | 0    | 0   | 0    | 100| 0  | 0 | 40 | 60 | 0  | 0  | 0  | 0  |

Source: Prepared by the authors
As can be seen in Table 3, the cases distribution of the “Wall Material” variable appears mainly in the “Light weight” “Intermediate-light”, “Intermediate” and “Heavy” codes. Given this and taking into account that at the beginning this parameter considered 3 codes only, it is recommended to group the codes associated to light materials and those associated to the heavy ones. In the case of the intermediate material, it is recommended to keep the difference between this code and the “intermediate-light”, since the latter has an important role in the definition of the 3, 4, 7 and 9 typologies. As to the case of the “Surface area” variable, it can be seen that in the segments detached dwelling and terraced dwelling-practically no code for surface area predominates. That is to say; the typologies of these segments can be applied to dwellings of any surface. The proposed alternative is to group the codes of this variable and generate less surface area cuts up to 50m², between 50 and 100m² and over 100m².

Table 5. Representativeness of the parameters Frames, Storeys, Surface, for each typology in %

| Segment                      | Typology | Window frames | Number of storeys | Surface area [m²] |
|------------------------------|----------|---------------|-------------------|-------------------|
|                              |          | Metal | Wood | PVC | Other | 1 | 2 | 3 | <35 | >35 to 50 | >50 to 70 | >70 to 100 | >100 to 140 | >140 |
| Detached dwelling            |          |       |      |     |       | 1 | 2 | 3 |     |           |           |            |             |             |      |
| 1 or CA1                     |          | 93    | 3    | 3   | 0     | 99 | 1 | 0 | 15  | 26         | 25         | 13          | 9           | 12          |      |
| 2 or CA2                     |          | 6     | 42   | 51  | 1     | 186| 14| 0 | 18  | 28         | 22         | 12          | 9           | 11          |      |
| 3 or CA3                     |          | 94    | 2    | 4   | 0     | 3  | 96| 1 | 10  | 42         | 19         | 8           | 7           | 14          |      |
| 4 or CA4                     |          | 5     | 3    | 92  | 0     | 2  | 98| 0 | 21  | 28         | 18         | 5           | 12          | 16          |      |
| 5 or CA5                     |          | 90    | 5    | 5   | 0     | 98 | 2 | 0 | 18  | 22         | 16         | 11          | 17          | 16          |      |
| Semi-detached dwelling or terrace |          |       |      |     |       | 1 | 2 | 3 |     |           |           |             |             |             |      |
| 6 or CPC1                    |          | 81    | 1    | 17  | 0     | 15 | 83| 2 | 17  | 21         | 26         | 11          | 15          | 11          |      |
| 7 or CPC2                    |          | 100   | 0    | 0   | 0     | 0  | 98| 2 | 24  | 13         | 15         | 14          | 13          | 22          |      |
| 8 or CPC3                    |          | 100   | 0    | 0   | 0     | 81 | 0 | 19| 18  | 22         | 29         | 14          | 9           | 9           |      |
| 9 or CPC4                    |          | 44    | 19   | 37  | 1     | 32 | 63| 5 | 15  | 27         | 27         | 9           | 12          | 11          |      |
| Apartment                    |          |       |      |     |       | 1 | 2 | 3 |     |           |           |             |             |             |      |
| 10 or D1                     |          | 100   | 0    | 0   | 0     | 100 | 0 | 0 | 24  | 0         | 16         | 0           | 30          | 30          |      |
| 11 or D2                     |          | 0     | 28   | 72  | 0     | 100 | 0 | 0 | 20  | 0         | 19         | 30          | 15          | 15          |      |
| 12 or D3                     |          | 100   | 0    | 0   | 0     | 100 | 0 | 0 | 0   | 0         | 100        | 0           | 0           | 0           |      |
| 13 or D4                     |          | 100   | 0    | 0   | 0     | 100 | 0 | 0 | 40  | 0         | 60         | 0           | 0           | 0           |      |

Source: Prepared by the authors

The following table shows the consolidated distribution of the variables, taking the above recommendations into account.

Table 6. Summary of the typologies, grouping categories, representativeness in %

| Segment                      | Typology | Wall Material | Window frames | Number of storeys | Surface (m²) |
|------------------------------|----------|---------------|---------------|-------------------|--------------|
|                              |          | L | I-L | I | P | Metal | Wood | PVC | 1 | 2 | 3 | <50 | >50 to 100 | >100 |
| Detached dwelling            |          | 2 | 3 | 90 | 4 | 93  | 3 | 3  | 99 | 1 | 0 | 41 | 38 | 21          |
| 1 or CA1                     |          | 83 | 3 | 12 | 2 | 6  | 42 | 51 | 86 | 14| 0 | 46 | 34 | 20          |
| 2 or CA2                     |          | 17 | 33| 40 | 10 | 94 | 2 | 4  | 3  | 96| 1 | 52 | 27 | 21          |
| 3 or CA3                     |          | 27 | 56| 12 | 6 | 5  | 3 | 92 | 2  | 98| 0 | 49 | 23 | 28          |
| 4 or CA4                     |          | 94 | 1 | 3 | 2 | 90 | 5 | 3  | 98 | 2 | 0 | 40 | 27 | 33          |
| 5 or CA5                     |          | 46 | 50| 1 | 3 | 81 | 1 | 17 | 15 | 83| 2 | 38 | 37 | 26          |
| Semi-detached dwelling or terrace |          | 0 | 0 | 100 | 0 | 100 | 0 | 0  | 0  | 98| 2 | 37 | 29 | 35          |
| 6 or CPC1                    |          | 2 | 0 | 98 | 0 | 100 | 0 | 0  | 81 | 0 | 19 | 40 | 43 | 18          |
| 7 or CPC2                    |          | 60 | 33| 4 | 3 | 44 | 19 | 37 | 32 | 63 | 5 | 42 | 36 | 23          |
| 8 or CPC3                    |          | 10 | 0 | 9 | 91 | 100 | 0 | 0  | 100 | 0 | 0 | 24 | 16 | 60          |
| 9 or CPC4                    |          | 11 | 0 | 0 | 91 | 100 | 0 | 0  | 28 | 72 | 100 | 0 | 0 | 20 | 49 | 30          |
| Apartment                    |          | 12 | 0 | 0 | 91 | 100 | 0 | 0  | 100 | 0 | 0 | 0 | 100 | 0                      |
| 10 or D1                     |          | 13 | 0 | 0 | 91 | 100 | 0 | 0  | 100 | 0 | 0 | 0 | 40 | 60          |

Source: Prepared by the authors
4.2. Incorporation of the FVM (V2) and FA (V8) variables into the typologies

As the FVM (V2) and FA (V8) variables were not included in the multivariables conglomerate analysis because they were not available in the INE FUE database, the CEV dataset was used to generate an analysis of the distribution of the FVM in the different segments. To this end, it was necessary to assign an FVM to the typologies, according to wall materiality, on the basis of the distribution of that variable. Table 7 shows the average FVM proposal for the 13 typologies, at the global level as well as the thermal zone. For those zones without FVM information in the CEV data, a value was generated on the basis of deducting a standard deviation to the average value of the FVM of the typology at the national level.

Table 7. FVM averages per segment/typologies, by zone, according to CEV data.

| Segment                  | Typology | Window-to-Wall Ratio (FVM), by Segment/Material/Zone |
|--------------------------|----------|------------------------------------------------------|
|                          |          | A  | B  | C  | D  | E  | F  | G  | H  | I  | Total |
| Detached dwelling        | 1 or CA1 | 0,08| 0,12| 0,08| 0,17| 0,09| 0,11| 0,09| 0,11| 0,11| 0,16 |
|                          | 2 or CA2 | 0,08| 0,07| 0,09| 0,15| 0,06| 0,06| 0,07| 0,08| 0,08| 0,10 |
|                          | 3 or CA3 | 0,08| 0,10| 0,10| 0,17| 0,11| 0,01| 0,01| 0,01| 0,01| 0,16 |
|                          | 4 or CA4 | 0,08| 0,10| 0,09| 0,16| 0,08| 0,02| 0,02| 0,03| 0,03| 0,14 |
|                          | 5 or CA5 | 0,08| 0,06| 0,09| 0,15| 0,06| 0,07| 0,08| 0,09| 0,09| 0,09 |
| Semi-detached dwelling or terrace | 6 or CPC1 | 0,11| 0,11| 0,13| 0,11| 0,09| 0,04| 0,05| 0,05| 0,05| 0,10 |
|                          | 7 or CPC2 | 0,12| 0,14| 0,14| 0,12| 0,12| 0,11| 0,09| 0,11| 0,11| 0,12 |
|                          | 8 or CPC3 | 0,12| 0,14| 0,14| 0,12| 0,12| 0,11| 0,09| 0,11| 0,11| 0,12 |
|                          | 9 or CPC4 | 0,11| 0,11| 0,13| 0,11| 0,08| 0,05| 0,06| 0,06| 0,06| 0,10 |
| Apartment                | 10 or D1 | 0,29| 0,19| 0,21| 0,39| 0,18| 0,24| 0,09| 0,15| 0,15| 0,34 |
|                          | 11 or D2 | 0,30| 0,21| 0,21| 0,42| 0,20| 0,27| 0,09| 0,17| 0,17| 0,35 |
|                          | 12 or D3 | 0,29| 0,19| 0,21| 0,39| 0,18| 0,24| 0,09| 0,15| 0,15| 0,34 |
|                          | 13 or D4 | 0,29| 0,19| 0,21| 0,39| 0,18| 0,24| 0,09| 0,15| 0,15| 0,34 |
| Total                    | 0,19     | 0,12| 0,19| 0,36| 0,10| 0,12| 0,09| 0,11| 0,11| 0,23 |

Source: Prepared by the authors.

Finally, the CEV dataset was employed to generate an analysis of the distribution Solar Accessibility Factor (FA) in the different segments, using the same procedure as explained for the assignment of the FVM. As can be seen in table 8, the FA shows small variation within each segment, except in the apartments of the zones A and C.

Table 8. Average per segment/materiality by zone, according to CEV data.

| Segment                  | Wall Material | Solar Accessibility Factor by Segment/Material/Zone |
|--------------------------|---------------|------------------------------------------------------|
|                          |               | A  | B  | C  | D  | E  | F  | G  | H  | I  | Total |
| Detached dwelling        | Intermediate  | 0,69| 0,77| 0,64| 0,72| 0,73| 0,71| 0,71| 0,71| 0,71| 0,72 |
|                          | Light         | 0,73| 0,78| 0,70| 0,76| 0,67| 0,73| 0,71| 0,71| 0,71| 0,72 |
|                          | Heavy         | 0,59| 0,71| 0,75| 0,71| 0,58| 0,71| 0,71| 0,71| 0,71| 0,71 |
|                          | Other         | 0,71| 0,71| 0,85| 0,68| 0,70| 0,71| 0,71| 0,71| 0,74| 0,71 |
| Semi-detached dwelling or terrace | Intermediate | 0,71| 0,63| 0,75| 0,70| 0,62| 0,71| 0,71| 0,69| 0,69| 0,69 |
|                          | Light         | 0,77| 0,75| 0,71| 0,72| 0,71| 0,73| 0,66| 0,69| 0,68| 0,72 |
|                          | Heavy         | 0,69| 0,71| 0,69| 0,72| 0,69| 0,69| 0,69| 0,69| 0,69| 0,69 |
|                          | Other         | 0,68| 0,67| 0,69| 0,71| 0,75| 0,73| 0,73| 0,69| 0,75| 0,72 |
| Apartment                | Intermediate  | 0,67| 0,64| 0,65| 0,63| 0,64| 0,64| 0,64| 0,64| 0,64| 0,64 |
|                          | Light         | 0,44| 0,64| 0,29| 0,63| 0,64| 0,64| 0,73| 0,64| 0,67| 0,65 |
|                          | Heavy         | 0,77| 0,64| 0,64| 0,57| 0,63| 0,84| 0,64| 0,64| 0,64| 0,65 |
|                          | Other         | 0,63| 0,67| 0,67| 0,64| 0,63| 0,57| 0,64| 0,64| 0,71| 0,64 |
| Total                    |               | 0,68| 0,68| 0,68| 0,66| 0,69| 0,70| 0,71| 0,68| 0,71| 0,68 |

Source: Prepared by the authors.

4.3. Distribution by zones

It must be considered that the analyses of conglomerates to determine the typologies were carried out separately for the three segments defined previously. If the percentages of representativeness were calculated per thermal zone and at the national level, those would be done separately for each segment. In this scenario, each segment would contain the same
number of cases and would not be useful to define the representativeness of the typologies by zone and at the national level.

Therefore, it was opted to use the 2017 Census and Casen 2017 databases, both of the INE to establish the representativeness of the typologies by zone and at the national level on the basis of the distribution of the variables “Wall Material” and “Grouping” in these two databases. This allowed building a distribution corrected by zone and at the national level, which is shown in table 9.

### Table 9. National Representativeness typologies/zone, corrected using the 2017 Census and Casen 2017

| Segment       | Typology | National distribution, per Zone, in (%) |
|---------------|----------|----------------------------------------|
|               |          | A  | B  | C  | D  | E  | F  | G  | H  | I  | Total |
| Detached      | 1 or CA1 | 0.30 | 0.98 | 1.53 | 7.73 | 0.32 | 0.67 | 0.05 | 0.00 | 0.00 | 11.6 |
| dwelling      | 2 or CA2 | 0.12 | 0.08 | 0.49 | 1.74 | 0.41 | 1.85 | 1.94 | 0.15 | 0.39 | 7.2  |
|               | 3 or CA3 | 0.18 | 0.1  | 1.48 | 8.45 | 1.30 | 0.98 | 0.29 | 0.04 | 0.13 | 13.0 |
|               | 4 or CA4 | 0.00 | 0.00 | 0.55 | 2.94 | 1.65 | 2.12 | 1.65 | 0.04 | 0.13 | 9.1  |
|               | 5 or CA5 | 0.12 | 0.12 | 0.77 | 1.62 | 1.06 | 2.91 | 0.68 | 0.12 | 0.39 | 7.8  |
| Semi-detached | 6 0 CPC1 | 0.27 | 0.35 | 0.37 | 3.21 | 1.05 | 1.09 | 0.30 | 0.04 | 0.30 | 7.0  |
| dwelling      | 7 or CPC2 | 1.97 | 0.00 | 1.36 | 7.78 | 0.22 | 0.04 | 0.00 | 0.00 | 0.00 | 11.4 |
| or terrace    | 8 or CPC3 | 0.61 | 1.06 | 0.86 | 6.22 | 0.06 | 0.46 | 0.00 | 0.00 | 0.02 | 9.3  |
|               | 9 or CPC4 | 0.27 | 0.35 | 0.37 | 2.40 | 0.99 | 0.73 | 1.01 | 0.04 | 0.22 | 6.4  |
| Apartments    | 10 or D1 | 0.50 | 0.00 | 0.89 | 3.33 | 0.50 | 0.13 | 0.08 | 0.00 | 0.02 | 5.4  |
|               | 11 or D2 | 0.00 | 0.15 | 0.00 | 5.98 | 0.00 | 0.13 | 0.08 | 0.00 | 0.01 | 6.4  |
|               | 12 or D3 | 0.31 | 0.00 | 0.54 | 1.98 | 0.30 | 0.08 | 0.05 | 0.00 | 0.01 | 3.3  |
|               | 13 or D4 | 0.21 | 0.00 | 0.38 | 1.39 | 0.20 | 0.05 | 0.03 | 0.00 | 0.01 | 2.3  |
| Total         |          | 4.9 | 3.2 | 9.6 | 54.8 | 8.1 | 11.2 | 6.1 | 0.4 | 1.6 | 100  |

Source: Prepared by the authors

4.4. Verification and generation of reference dwellings

The samples of 1,000 cases per segment were accessed and at least one case was selected to cross the typologies and zones, using as selection criterion the least possible distance obtained in the analysis of conglomerates. The property tax code of these cases was used, combining the city block and plot fields, and the geographic location was found using the SII search engine and Google maps. It was then possible to generate a series of tridimensional models, based on the variables making up the typologies, plus real cases images. All this information was recorded in a series of summary sheets, one for each typology, as shown in the Appendix.

5. Conclusions

A total of 13 typologies was obtained as a result of this study. They characterize the stock of dwellings built in Chile, as a function of parameters that influence their energy demand, with a confidence level of 91%. The percentage distribution of each typology, for the country and by thermal zone is also shown. The statistics relevance of the combination of materials in the wall of the dwellings was revealed by the analysis, creating the code “Intermediate-Light”. This aspect was not considered initially. Furthermore, the inclusion of the variable “Number of storeys” was significant to define typologies. On the other hand, the built surface area was not an important variable for the definition of typologies, except in the apartment segment. The typologies representing the segments detached dwelling and semi-detached and terraced dwelling do not show a clear preponderance in all surface area codes. Therefore, it seems to be opportune to evaluate the effect that these variables and codes may have during the second stage of this study. Finally, it must be stressed that it was not possible to integrate the different sources of official data, mainly due to the lack of a common identifier, besides difficulties associated to the formats, variables and codes of each source. Furthermore, the number of variables taken into account was restricted by the amount of available data; this did not allow to directly include parameters such as the shape factor and thermal bridges. This was partially addressed by a process of image verification using GoogleStreetView, thus starting an analysis that should be expanded, using samples and cases revision to allow obtaining those variables in
order to identify the energy demand of the stock of dwellings in Chile. It must be pointed out that during the process of images revision with GoogleStreetView it was noticed that the dwellings as built could differ from what was defined in their building permits, mainly due to additions to detached or semi-detached dwellings.

References
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[2] INE 2018 Edificación Obtained on 2018.11.20 from http://ine.cl/estadisticas/ economicas/construccion/edificacion-superficie-autorizada
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Appendix: 5 selected examples of typologies summary sheet
CASAS AISLADAS - TIPOLOGÍA N°3

CARACTERÍSTICAS

| Tipología | Distribución de polarizaciones (%) | Material | Marco ventanas | Contenido planos | Superficie (m²) |
|-----------|-----------------------------------|----------|----------------|-----------------|----------------|
| 2 x CAS  |                                    | 1        | 14             | 1               | 3              |
| 3 x CAS  |                                    | 17       | 33             | 40              | 10             |

ID: 587-46-LE10

"Caracterizar el parque construido de viviendas en función de los principales parámetros que influyen en su demanda de energía"

CASAS PAREADAS / CONTINUAS - TIPOLOGÍA N°7

CARACTERÍSTICAS

| Tipología | Distribución de polarizaciones (%) | Material | Marco ventanas | Contenido planos | Superficie (m²) |
|-----------|-----------------------------------|----------|----------------|-----------------|----------------|
| 2 x CPC  |                                    | 1        | 14             | 1               | 3              |
| 3 x CPC  |                                    | 19       | 34             | 12              | 11             |

ID: 587-46-LE10

"Caracterizar el parque construido de viviendas en función de los principales parámetros que influyen en su demanda de energía"
CASAS PAREDADAS / CONTINUAS - TIPOLOGÍA N°8

DESCRIPCIÓN DE ESPECIFICACIONES

Casa Paredada/Continua, de 1 Piso (81%) o 3 pisos (19%)
• Materialidad: Predomina en muros la materialidad intermedia, con un 98% de los casos.
• Ventanas:
  - Marco de Metal, con un 100% de los casos.
  - (FVM) promedio es 0.12 en 0.12 y 0.14.
  - (FA) se define en 0.69.
• Superficie: ver tabla
• Distribución geográfica: ver tabla

CARACTERÍSTICAS

| Tipo | Material | Marco ventanas | Número de pisos | Superficie (m²) |
|------|----------|----------------|-----------------|----------------|
| L & P  | L & P  | 1 & P | 1 & P | 1 & P |
| 1 & 2 | 0 | 0 | 0 | 0 | 0 |
| 3 & 4 | 0 | 0 | 0 | 0 | 0 |
| 5 & 6 | 0 | 0 | 0 | 0 | 0 |
| 7 & 8 | 0 | 0 | 0 | 0 | 0 |

ID: 587-46-LE18

"Caracterizar el parque constructor de viviendas en función de los principales parámetros que influyen en su demanda de energía"

DEPARTAMENTO - TIPOLOGÍA N°11

DESCRIPCIÓN DE ESPECIFICACIONES

Departamento, de 1 Piso
• Materialidad: Predomina materialidad Pasada (100%)
• Ventanas:
  - Marco de PVC (72%) o Madera (28%)
  - (FVM) promedio es 0.36. Fluctúa entre 0.42 (zona D) y 0.17 (zona I).
  - (FA) se define en 0.64.
• Superficie: ver tabla
• Distribución geográfica: ver tabla

CARACTERÍSTICAS

| Tipo | Material | Marco ventanas | Número de pisos | Superficie (m²) |
|------|----------|----------------|-----------------|----------------|
| E & F  | E & F  | 1 & F | 1 & F | 1 & F |
| 1 & 2 | 0 | 0 | 0 | 0 | 0 |
| 3 & 4 | 0 | 0 | 0 | 0 | 0 |
| 5 & 6 | 0 | 0 | 0 | 0 | 0 |
| 7 & 8 | 0 | 0 | 0 | 0 | 0 |

ID: 587-46-LE18

"Caracterizar el parque constructor de viviendas en función de los principales parámetros que influyen en su demanda de energía"