Impact of Shape Factor on Energy Demand, CO\textsubscript{2} Emissions and Energy Cost of Residential Buildings in Cold Oceanic Climates: Case Study of South Chile

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Abstract: The increase in energy consumption that occurs in the residential sector implies a higher consumption of natural resources and, therefore, an increase in pollution and a degradation of the ecosystem. An optimal use of materials in the thermal envelope, together with efficient measures in the passive architectural design process, translate into lower energy demands in residential buildings. The objective of this study is to analyse and compare, through simulating different models, the impact of the shape factor on energy demand and CO\textsubscript{2} emissions depending on the type of construction solution used in the envelope in a cold oceanic climate in South Chile. Five models with different geometries were considered based on their relationship between exposed surface and volume. Additionally, three construction solutions were chosen so that their thermal transmittance gradually complied with the values required by thermal regulations according to the climatic zone considered. Other parameters were equally established for all simulations so that their comparison was objective. Ninety case studies were obtained. Research has shown that an appropriate design, considering a shape factor suitable below 0.767 for the type of cold oceanic climate, implies a decrease in energy demand, which increased when considering architectural designs in the envelope with high values of thermal resistance.

Keywords: shape factor; building; thermal envelope; energy demand; CO\textsubscript{2} emissions

1. Introduction

Energy consumption is reflected in the gross domestic product (GDP) of a country. There is a close relationship between GDP and the required electrical energy, which increases every year at the country level and is sustained \cite{1}. The world has created a legal framework to respond to the need to provide energy in the context of sustainable development, given the threats \cite{2}. As a first initiative in the regulatory framework, in 1997, 37 industrialised countries and the European Union established the Kyoto Protocol \cite{3}. A building, especially in the operation stage, can be a great potential consumer of energy, and only using measures and strategies in the design stage which involve insignificant increases in construction costs and significant benefits in energy demand (or energy need \cite{4}) and emission reduction can significantly affect its energy consumption \cite{5}.

The energy efficiency of a building depends not only on the thermal properties of the materials in the envelope but also on its shape; the orientation and distribution of spaces, windows and opening ratios; interior temperature; the façade colour and protection against solar radiation \cite{6}. All these parameters influence the passive design of a building, depending on the climatic zone in which it is located. The volumetric impact on a building at the design stage produces better efficiency during the life cycle of the home, reducing energy and natural resource consumption \cite{7,8}. To optimise architectural designs for thermal envelopes, it is essential to study the climate of the building area in detail \cite{9,10}. 

Compactness is a characteristic of the volume of the building; it is used to adjust the exposed envelope, depending on the useful area, as much as possible [11]. This geometric relationship is represented by the shape factor ($SF_v$). Buildings with a high $SF_v$ value are less compact, resulting in higher heating energy demands in cold climates with poorly sunny winters [12,13]. The impact of $SF_v$ varies considerably for buildings with different properties in the thermal envelope and weather conditions [14]. A study of the impact of different thermal envelopes in buildings showed that more significant benefits are obtained by using materials with better thermal quality in the envelope when there is more exposed surface per m$^2$ of useful surface [15]. However, for a correct architectural design, a multitude of variables such as orientation, wind and lighting, among others, must be taken into account.

Globally, Chile has an essential representation of cities located in cold oceanic climates [16]. In Chile, one of the most significant increases in energy demand occurred between 2008 and 2014, reaching 18.43% in the commercial, public and residential sectors [17]. Most of this increase (53.7%) was renewable energy from biomass. Furthermore, the imported energy sources are primarily crude oil, natural gas and coal, with 51.8%, 17.0% and 31.2%, respectively. This marked dependence on scarce and non-renewable fuels suggests future problems in energy supply [18]. Additionally, the high carbon emissions resulting from using these fossil fuels generate major environmental and health problems, mainly climate change caused by greenhouse gas emissions [19].

In Chile, the Ordenanza General de Urbanismo y Construcciones (OGUC) (General Ordinance of Urbanism and Constructions) has incorporated the Regulación Térmica (RT) (Thermal Regulation) [20] to be able to classify the energy demand of a building through an energy certification programme, taking into account the different climatic zones (Chilean regulations use the synonym thermal zones). In the specific case of Chile, various investigations were carried out to specify the different climatic zones [21,22], including making projections of future climate change [23] and seeing its application in different fields of study, such as heritage [24]. For cold climates, as in southern Chile, compact buildings with good insulation and infiltration control are recommended. However, care should be taken when using a very low $SF_v$, as this can cause ventilation problems and less use of natural light [25].

Considering this background, the objective of this study is to analyse the influence of buildings’ thermal envelope $SF_v$ on energy demand and CO$_2$ emissions in oceanic cold climates by simulating different solutions for optimisation. To carry out this main objective, the following specific objectives were developed: (i) Modelling buildings with different $SF_v$; (ii) Applying different architectural designs to the models; (iii) Simulation in different cities in southern Chile; and (iv) Analysing the results. The scope of this study is limited to $SF_v$ in climatic zones of southern Chile with different constructive solutions. A multitude of additional variables can be studied in future works for a complete analysis of complex architectural designs.

2. Materials and Methods

2.1. Shape Factor

As the surface of the building in contact with the outside is more significant, there will be more energy exchanges, which may be beneficial or unfavourable in certain types of climates [25], depending on whether the building seeks to conserve the heat inside it or dissipate it to the environment.

$SF_v$ is a simple equation that relates the enveloping surface to the volume (Equation (1)) [26].

$$SF_v = \frac{Se}{V}$$  (1)

where the $SF_v$ is directly related to the heating energy demand in a dwelling, $Se$ is the surface area of the exposed envelope and $V$ is the habitable volume. The higher the $SF_v$ (for an identical habitable volume), the higher the heating energy demand of the dwelling.
2.2. Climate Data and Climatic Zones

To validate the optimal $SFo$ in buildings in cold oceanic climates, as shown in Figure 1, capitals of the southern zone of Chile were chosen—Concepción, Temuco, Valdivia, Puerto Montt, Coyhaique and Punta Arenas. These cities generally represent the climatic characteristics that affect the buildings. According to the study carried out by Sarricolea et al. [16] on the climatic regionalisation of continental Chile, all capitals studied using the Köppen–Geiger climate classification have climate C with an oceanic or marine influence. Table 1 shows the climatic zone and climatological station of each of the different cities. In Chile, the regulation that regulates the climatic zones of the country is the OGUC [20], which divides the territory into 7 zones—where Zone 1 is the warmest and Zone 7 is the coldest.

![Figure 1. Location map of Chile.](image)

Table 1. Climatic zones and meteorological station of the regional capitals of southern Chile.

| City           | Region                      | Meteorological Station Data | Climatic Zone OGUC | Temperature—Summer $[°C]$ | Temperature—Winter $[°C]$ | Annual Global Radiation [kWh/m²] |
|----------------|-----------------------------|------------------------------|--------------------|---------------------------|--------------------------|----------------------------------|
| Concepción     | Bio-Bio                     | Global station               | 4                  | $16.2 \pm 0.7$           | $11.1 \pm 0.3$           | $1729.1 \pm 26.4$                |
| Temuco         | Araucanía                   | Manquehe                     | 5                  | $15.7 \pm 0.7$           | $9.7 \pm 0.6$            | $1552.8 \pm 47.5$                |
| Valdivia       | Los Ríos                    | Pichoy                       | 5                  | $15.4 \pm 0.8$           | $10.0 \pm 0.4$           | $1509.5 \pm 55.9$                |
| Puerto Montt   | Los Lagos                   | El Tepu                      | 6                  | $13.7 \pm 0.5$           | $9.0 \pm 0.2$            | $1335.9 \pm 72.9$                |
| Coyhaique      | Aysén del General Carlos Ibáñez del Campo | Teniente V              | 7                  | $12.4 \pm 1.0$           | $5.4 \pm 0.9$            | $1343.2 \pm 76.5$                |
| Punta Arenas   | Magallanes y la Antártida Chilena | Global station         | 7                  | $10.0 \pm 0.6$           | $4.8 \pm 0.8$            | $1101.3 \pm 29.9$                |

Climatological data for the cities were extracted in *.epw format by the software Meteonorm 7 [27]. Table 1 shows the meteorological stations from which the data were obtained, with radiation periods between 1991 and 2010 and temperature periods between 2000 and 2009.
2.3. CO₂ Emissions and Energy Costs of Fuels

As shown in Table 2, the theoretical values of CO₂ emissions and the lower heating value (LHV) for different fuels were calculated according to data obtained from different official sources [28,29]. Similarly, the cost of using different types of fuels is the price collected from official reports from the Chilean government [30] and other international studies [31–33]. For the present study, only the cost of fuel has been taken into account. The cost of equipment installation and maintenance has not been considered. The equipment used were boilers with a thermal efficiency of 90% and an outlet water temperature of 80 °C for heating [19]. For electricity, instead, an electrical system was used.

Table 2. Emissions, LHV and cost of different fuels.

| Fuel                | CO₂ Emissions [kgCO₂/kWh] | LHV       | Cost [USD/kWh] |
|---------------------|---------------------------|-----------|----------------|
| Electricity (Chile) | 0.346                     | -         | 0.107          |
| Natural gas         | 0.204                     | 9.771 kWh/m³ | 0.095          |
| Propane gas         | 0.254                     | 13.131 kWh/m³ | 0.192          |
| Biomass (wood)      | Neutral                   | 2.759 kWh/kg | 0.083          |
| Biomass (pellet)    | Neutral                   | 5.010 kWh/kg | 0.061          |
| Gasoil              | 0.287                     | 11.939 kWh/kg | 0.082          |

2.4. Case Studies

To carry out the present study, five buildings with different SFᵥ and three architectural designs in each of the six capitals of the southern regions of Chile were studied, thus obtaining a total of 90 case studies. The buildings and the energy simulations were modelled following the Building Information Modelling (BIM) and Building Performance Analysis (BPA) methodology through Autodesk© software [34] based on the calculation methodology of ISO 52016-1:2017 [4], ISO 52017-1:2017 [35] and ISO 13789:2017 [36]. All models used the same calculation parameters, with 20 m²/person, an 18–22 °C temperature range, 0.5 air renewals/hour, person 1680 Wh daily heat gain and 2.29 Wh/m² equipment thermal gain. The characteristics of the different case studies are shown below.

2.4.1. Building Geometry

Table 3 and Figure 2 show the five residential building models (M1, M2, M3, M4 and M5) created. Each model varies from the highest to the lowest SFᵥ. All models have a square plan with an increase of 10 m of façade between them, a 3 m height between floors and a flat roof.

Table 3. SFᵥ of the models.

| Model | Floor Dimensions [m × m] | Floor Space [m²] | Number of Floors | Volume [m³] | Exposed Surface [m²] | SFᵥ  |
|-------|--------------------------|------------------|------------------|-------------|---------------------|------|
| M1    | 10 × 10                  | 100              | 1                | 300         | 320                 | 1.067|
| M2    | 20 × 20                  | 400              | 1                | 1200        | 1040                | 0.867|
| M3    | 40 × 40                  | 1600             | 1                | 4800        | 3680                | 0.767|
| M4    | 30 × 30                  | 900              | 2                | 5400        | 2520                | 0.467|
| M5    | 50 × 50                  | 2500             | 3                | 22,500      | 6800                | 0.302|

However, it is necessary to clarify that the building models used do not correspond to actual buildings. These models are theoretical, and all the buildings have common characteristics, with the SFᵥ variable to be compared between them. These theoretical models have the same SFᵥ as more common buildings. For example, on the one hand, M3 maintains the same SFᵥ as a two-floor building with a 9.3 × 9.3 m floor dimension. On the other hand, M5 maintains the same SFᵥ as a six-floor building with a 21 × 21 m floor dimension.
2.4.2. Architectural Designs for the Thermal Envelopes

Figure 3 and Tables 4 and 5 show the three thermal envelope construction solutions (S1, S2 and S3) for the models described in the previous section. The ratio of window and door area will be 26.67% on all models. According to the material used and the thickness of each layer, each solution has different thermal transmittance (U-value).

Figure 2. Graphic detail of SFv models.

Figure 3. Graphic detail of the architectural designs.
Table 4. Characteristics of the envelope materials.

| Material | e [m] | λ [W/(m × K)] | R [(m² × K)/W] |
|----------|-------|----------------|----------------|
| S1       |       |                |                |
| Interior wood lining—Insigne pine 1/2 × 4” | 0.013 | 0.104 | 0.122 |
| Unventilated vertical air chamber | 0.100 | 0.714 | 0.140 |
| Exterior wood lining—Tinglado dry pine 5 × 3/4” | 0.019 | 0.104 | 0.183 |
| **U = 1.625 [W/(m² × K)]** | | | 0.132 |
| Cement mortar | 0.025 | 1.400 | 0.018 |
| Craft brick—285 × 143 × 90 mm—Stonework 20 mm | 0.143 | 0.664 | 0.215 |
| Cement mortar | 0.025 | 1.400 | 0.018 |
| Expanded polyethylene with EIFS system—d = 20 kg/m³ | 0.030 | 0.038 | 0.781 |
| **U = 0.832 [W/(m² × K)]** | | | 0.223 |
| Thermal stucco | 0.025 | 0.220 | 0.114 |
| Reinforced concrete | 0.200 | 1.630 | 0.123 |
| Expanded polyethylene with EIFS system—d = 20 kg/m³ | 0.100 | 0.038 | 2.604 |
| **U = 0.332 [W/(m² × K)]** | | | 0.325 |
| Plasterboard—d = 700 kg/m³ | 0.013 | 0.260 | 0.048 |
| Wooden beam—Insigne pine 3 × 4” | 0.102 | 0.104 | 0.977 |
| Non-ventilated vertical air chamber | 0.100 | 0.769 | 0.130 |
| Fibrocement roof—d = 920 kg/m³ | 0.010 | 0.220 | 0.045 |
| **U = 0.746 [W/(m² × K)]** | | | 0.224 |
| Plasterboard—d = 700 kg/m³ | 0.013 | 0.260 | 0.048 |
| Wooden beam—Insigne pine 3 × 4” | 0.102 | 0.104 | 0.977 |
| Expanded polyethylene with EIFS system—d = 20 kg/m³ | 0.060 | 0.038 | 1.563 |
| Fibrocement roof—d = 920 kg/m³ | 0.010 | 0.220 | 0.045 |
| **U = 0.361 [W/(m² × K)]** | | | 0.184 |
| Plasterboard—d = 700 kg/m³ | 0.013 | 0.260 | 0.048 |
| Reinforced concrete slab | 0.120 | 1.630 | 0.074 |
| Expanded polyethylene with EIFS system—d = 20 kg/m³ | 0.150 | 0.038 | 3.906 |
| Fibrocement roof—d = 920 kg/m³ | 0.010 | 0.220 | 0.045 |
| **U = 0.237 [W/(m² × K)]** | | | 0.293 |

Table 5. Doors and windows.

| Material | U [W/(m² × K)] | Visual Transmittance | Solar Factor |
|----------|----------------|----------------------|-------------|
| S1       |                |                      |             |
| Windows  |                |                      |             |
| Double-glazed | 5.736 | 0.90 | 0.86 |
| Wood     | 3.804          |                      |             |
| S2       |                |                      |             |
| Windows  |                |                      |             |
| Double-glazed | 3.129 | 0.81 | 0.76 |
| Hollow wood | 2.326 |      |     |
| S3       |                |                      |             |
| Windows  |                |                      |             |
| Low emission double-glazed | 2.215 | 0.76 | 0.65 |
| Doors    |                |                      |             |
| Wooden frame—Double-glazed—Glaze against door | 1.936 |      |     |

3. Results

The results obtained in the models for (i) energy demand, (ii) CO₂ emissions and (iii) energy cost are shown below.

3.1. Energy Demand

Figures 4 and 5 show that the total annual energy demand varied from 37.20 kWh/m² in M5, located in the city of Concepción with an S3, to 348.98 kWh/m² in M1, in Punta Arenas, with an S1. Only 2.38% of the total energy is required to cool the building, considering all the architectural designs and climatic zones. Detailed results of heating
and cooling demands, in all models with different architectural designs in the six cities, are shown in Tables A1–A6 in the Appendix A.

Figure 4. Annual energy demand of the models. Concepción, Temuco and Valdivia.
The results show that the city of Concepción (climatic zone 4) was the one that had the lowest required total energy demand under any of the proposed construction solutions and established models. In contrast, Punta Arenas (climatic zone 7) had the highest total energy demand.
Regarding the design characteristics of the envelope in the different construction solutions considered, S1 is the solution with the highest energy demand in all the models and areas studied, due to the high value of thermal transmittance.

Figure 6 shows the impact of SFv on the annual energy demand in each city, depending on the type of construction solution used. The maximum variation in demand (considering M1 and M5 for all cities) was: S1 between 135.30% and 198.70%; S2 between 162.89% and 235.12%; and S3 between 174.29% and 244.71%.

3.2. CO2 Emissions

Due to the large amount of data obtained, only the results of S2 will be shown, since it is the most representative of all, considering, in turn, a representative city of each climatic zone—Concepción (4), Valdivia (5), Puerto Montt (6) and Punta Arenas (7).

Figure 7 shows the CO2 emissions generated due to energy demand. The energy used to cool the buildings was assumed as electric for all models. However, the energy source used for heating was variable, based on the values presented in Table 1. For all climatic zones, the least optimal is the exclusive use of electricity, independent of the SFv of the dwelling. However, using biomass (wood and pellets) produces low emissions, mainly due to the neutral emission factor [19].

A 160.62 to 235.12% increase in CO2 emissions between climatic zones 4 and 7 was observed when using any heating system. In turn, implementing an S1 to an S3 in the thermal envelope reduced CO2 emissions between 22.74% and 56.67% for all energy options.

3.3. Energy Cost

The energy cost of these alternatives is represented in Figure 8. In this figure, the annual cost of heating and cooling the buildings is shown depending on the SFv and the alternative used, expressed in USD/m², based on the values presented in Table 2. The use of propane gas as fuel for heating is the most expensive option of all in any area studied; on the contrary, the use of pellets is the most economical.
In 3.3. were observed annual energy cost differences from 6.00 to 26.09% between each SFv interval considered; in Punta Arenas, this range was between 4.99% and 17.49%.

Figure 7. Annual emissions depending on the fuel used.

Figure 8. Annual energy cost depending on the fuel used.
A 160.43 to 236.25% increase in cost between climate zones 4 and 7, when using any heating system, was similar to what happened in emissions. Implementing an S1 to an S3 in the thermal envelope reduces the cost for all energy options between 22.74% and 56.72%.

Propane gas has had a wide variation in cost between 12.52% and 236.25% for all the climatic zones analysed. The rate of decrease in cost varies depending on the climatic zone. In Concepción its cost drop fluctuates from 6.00 to 26.09% between each SFv interval considered; in Punta Arenas, this range was between 4.99% and 17.49%.

The cost of the heating system was reduced between 52.16% and 63.30% using M1 and M5, respectively, when implementing S1, 34.23 to 48.60% with an S2 and 27.82% and 42.65% with an S3.

4. Discussion

In the present study, implementing S2 represents a 19.68 to 48.01% decrease in required power demand compared to S1; and a 22.74 to 56.16% decrease in consumption compared to the S3, depending on the city where the building is located and the SFv. Comparing our results with the study carried out by Danielski et al. [14], similar results are obtained, where the slope between the total energy demand per square meter and the SFv increases when using a construction solution with less thermal resistance in the envelope.

The impact on energy demand from reducing SFv was studied in various investigations. In Italy, different energy models, with form factors between 0.54 and 0.78, were analysed in different cities, reaching 34.09 to 43.14% differences in energy demand [37]. In Lithuania, a 33.77% variation in the required energy was obtained by decreasing the SFv from 1.35 to 1.17 [8]. In Sweden, heating demand was decreased between 18.00% and 20.00% by reducing the SFv from 1.70 to 1.01 in different cities [14].

Additionally, when comparing the energy demand of M1 and M5, 27.82 to 62.95% reductions were reached depending on the city and the construction system considered. The impact of SFv was less in the coldest city, Punta Arenas, where consumption only decreased by 27.82 to 52.16%. In contrast, in Concepción, energy savings fluctuated between 42.57% and 62.95%.

Whenever the SFv decreases, so do the difference in emissions by improving the architectural design. When the SFv is reduced from 1.067 to 0.302: implementing an S1 caused a CO₂ decrease between 52.16% and 63.23%; while with an S3, they decrease from 27.82 to 42.64%. With these and similar data from other studies [15], it has been shown that more significant benefits are obtained by improving the thermal resistance of the envelope when there is a higher relation between the exposed surface and the m² of the surface of the building.

Finally, in Chile there are other studies on the form factor in buildings and its influence on energy demand. For example, Vásquez et al. [38] investigated with the SFv of office buildings in the city of Santiago, Chile. They conclude that the SFv is essential in architectural design along with other variables such as solar radiation, light, wind or the immediate context.

5. Conclusions

This research showed an appropriate design considering a SFv suitable for cold oceanic climates, which implied a decrease in energy demand and CO₂ emissions. The main conclusions derived from this research are the following:

- The architectural designs with high thermal transmittance values may require from 129.44 to 227.67% of the energy demand of the same building after implementing a solution with a low U-value. Energy demand is widely affected by the weather where housing is located; maximum variations between 135.30 and 244.71% exist for the same SFv and architectural design, depending on the city where it is located.
- CO₂ emissions depend directly on the climatic zone where the building is located and the fuel used. For all cities, using biomass in heating systems has the lowest emission and cost values, as opposed to what happens when using electricity for
heating. Differences in CO$_2$ emissions from 7.43 to 235.12% can be found between the different climatic zones for the same model. Similarly, the cost of the heating system is reduced by between 31.81 and 32.95% when switching from a fossil fuel, such as propane, to a renewable fuel, such as biomass in the form of pellets.

- Overall, the impact of $SFv$, on both energy demand and CO$_2$ emissions, is greater when architectural designs with a high thermal transmittance value are implemented, reducing energy demand between 22.75% and 56.16%, depending on the area located. Based on the analysis, it is highly recommended to design buildings with a $SFv$ below 0.767 for cold oceanic climates, such as in the southern zone of Chile. Among the values shown, energy demand and CO$_2$ emissions tend to stabilise for all the climatic zones and construction solutions studied, with only 9.03% maximum differences in the energy requirement for heating and 10.37% in CO$_2$ emissions.

These results are fully extrapolated to any area with climatic conditions similar to a cold oceanic climate. This study has considered the $SFv$ as the main variable, although for a comprehensive architectural design other variables must be taken into account, such as solar exposure, wind orientation and passive design characteristics.

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### Table A1. Energy demand—Concepción.

|        | Monthly Energy Demand [kWh/m²] | Annual Energy Demand [kWh/m²] |
|--------|---------------------------------|--------------------------------|
|        | Jan.   | Feb.   | Mar.   | Apr.   | May    | Jun.   | Jul.   | Aug.   | Sep.   | Oct.   | Nov.   | Dec.   | H/C   | Total |
| S M    |        |        |        |        |        |        |        |        |        |        |        |        |       |       |
| S1     |        |        |        |        |        |        |        |        |        |        |        |        |       |       |
| M1     | Heating | 4.10   | 4.18   | 6.49   | 11.73  | 16.63  | 19.54  | 21.38  | 18.22  | 15.97  | 11.14  | 7.94   | 5.13   | 142.45| 147.46|
|        | Cooling | 2.00   | 1.55   | 0.86   | 0.06   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 5.02  |       |
| M2     | Heating | 2.53   | 2.55   | 4.11   | 7.73   | 11.17  | 13.23  | 14.60  | 12.50  | 10.99  | 7.51   | 5.34   | 3.32   | 95.61 | 98.37 |
|        | Cooling | 1.28   | 0.88   | 0.25   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.35  | 2.76  |
| S2     |        |        |        |        |        |        |        |        |        |        |        |        |       |       |       |
| M1     | Heating | 2.06   | 2.04   | 3.25   | 6.13   | 10.71  | 11.71  | 9.91   | 8.76   | 5.89   | 4.19   | 2.59   | 1.80   | 56.46 | 57.11 |
|        | Cooling | 0.29   | 0.51   | 0.08   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.08  | 0.75  |
| M2     | Heating | 1.35   | 1.26   | 2.23   | 4.41   | 6.60   | 7.99   | 8.91   | 7.63   | 6.76   | 4.22   | 3.11   | 1.80   | 56.46 | 56.85 |
|        | Cooling | 0.20   | 0.20   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00  | 0.39  |
| S3     |        |        |        |        |        |        |        |        |        |        |        |        |       |       |       |
| M1     | Heating | 1.64   | 1.62   | 2.63   | 5.08   | 7.47   | 9.06   | 9.94   | 8.40   | 7.45   | 4.94   | 3.50   | 2.12   | 63.85 | 64.77 |
|        | Cooling | 0.35   | 0.43   | 0.07   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.07  | 0.92  |
| M2     | Heating | 1.03   | 1.02   | 1.88   | 3.85   | 5.83   | 7.11   | 7.96   | 6.83   | 6.06   | 3.91   | 2.75   | 1.50   | 49.72 | 50.27 |
|        | Cooling | 0.22   | 0.27   | 0.02   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.04  | 0.55  |
| S4     |        |        |        |        |        |        |        |        |        |        |        |        |       |       |       |
| M1     | Heating | 0.46   | 0.48   | 1.24   | 3.09   | 4.82   | 5.94   | 6.68   | 5.74   | 5.10   | 3.21   | 2.22   | 0.96   | 39.94 | 40.20 |
|        | Cooling | 0.15   | 0.12   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00  | 0.26  |
| S5     |        |        |        |        |        |        |        |        |        |        |        |        |       |       |       |
| M1     | Heating | 0.39   | 0.35   | 1.03   | 2.79   | 4.46   | 5.50   | 6.23   | 5.39   | 4.80   | 3.99   | 2.99   | 2.01   | 0.81  | 36.74 |
|        | Cooling | 0.26   | 0.17   | 0.01   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02  | 0.46  |

S = solution; M = model; H = heating; C = cooling.
## Table A2. Energy demand—Temuco.

| S | M | H/C | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | H/C Total | Total |
|---|---|-----|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----------|-------|
| S1 | M1 | Heating | 6.26 | 6.04 | 9.74 | 15.70 | 20.42 | 24.09 | 26.89 | 22.80 | 19.25 | 14.23 | 10.94 | 7.62 | 183.97 | 195.74 |
| | | Cooling | 3.93 | 4.97 | 1.86 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.77 |
| | M2 | Heating | 4.09 | 3.81 | 6.37 | 10.38 | 13.64 | 16.28 | 18.23 | 15.49 | 13.06 | 9.57 | 7.39 | 5.03 | 123.34 | 129.91 |
| | | Cooling | 2.36 | 2.89 | 0.98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.34 | 6.57 |
| | M3 | Heating | 2.92 | 2.76 | 4.77 | 7.92 | 10.51 | 12.67 | 14.22 | 12.12 | 10.22 | 7.45 | 5.76 | 3.81 | 95.15 | 99.61 |
| | | Cooling | 1.65 | 2.07 | 0.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.17 | 4.46 |
| | M4 | Heating | 2.38 | 2.36 | 4.33 | 7.48 | 9.91 | 11.96 | 13.44 | 11.45 | 9.68 | 7.04 | 5.44 | 3.49 | 88.96 | 90.59 |
| | | Cooling | 0.49 | 1.04 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.64 |
| | M5 | Heating | 1.74 | 1.78 | 3.30 | 5.87 | 7.86 | 9.60 | 10.83 | 9.23 | 7.78 | 5.61 | 4.35 | 2.61 | 70.56 | 72.52 |
| | | Cooling | 0.65 | 1.11 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.96 |
| S2 | M1 | Heating | 3.17 | 3.02 | 5.02 | 8.21 | 10.80 | 13.04 | 14.67 | 12.27 | 10.27 | 7.46 | 5.73 | 3.91 | 97.57 | 101.76 |
| | | Cooling | 1.35 | 2.21 | 0.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.19 |
| | M2 | Heating | 2.15 | 2.06 | 3.56 | 5.94 | 7.93 | 9.74 | 10.97 | 9.28 | 7.78 | 5.59 | 4.32 | 2.81 | 72.14 | 73.93 |
| | | Cooling | 0.62 | 0.98 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.79 |
| | M3 | Heating | 1.63 | 1.56 | 2.83 | 4.88 | 6.61 | 8.20 | 9.27 | 7.87 | 6.60 | 4.71 | 3.65 | 2.29 | 60.10 | 61.54 |
| | | Cooling | 0.53 | 0.76 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.43 |
| | M4 | Heating | 1.26 | 1.35 | 2.57 | 4.72 | 6.39 | 7.93 | 8.97 | 7.58 | 6.34 | 4.50 | 3.48 | 2.05 | 57.13 | 58.20 |
| | | Cooling | 0.23 | 0.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.07 |
| | M5 | Heating | 1.04 | 1.13 | 2.17 | 4.13 | 5.68 | 7.11 | 8.07 | 6.83 | 5.71 | 4.03 | 3.13 | 1.77 | 50.81 | 52.18 |
| | | Cooling | 0.44 | 0.80 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.37 |
| S3 | M1 | Heating | 2.61 | 2.49 | 4.14 | 6.82 | 9.03 | 11.01 | 12.40 | 10.37 | 8.65 | 6.24 | 4.79 | 3.23 | 81.79 | 85.80 |
| | | Cooling | 1.26 | 2.07 | 0.69 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.02 |
| | M2 | Heating | 1.78 | 1.68 | 3.03 | 5.20 | 6.99 | 8.65 | 9.76 | 8.25 | 6.91 | 4.94 | 3.82 | 2.43 | 63.42 | 65.56 |
| | | Cooling | 0.76 | 1.05 | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.14 |
| | M3 | Heating | 1.40 | 1.38 | 2.52 | 4.48 | 6.09 | 7.60 | 8.60 | 7.30 | 6.12 | 4.35 | 3.39 | 2.07 | 55.29 | 57.09 |
| | | Cooling | 0.66 | 0.89 | 0.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.79 |
| | M4 | Heating | 0.99 | 1.09 | 2.11 | 4.23 | 5.79 | 7.24 | 8.20 | 6.93 | 5.78 | 4.08 | 3.16 | 1.76 | 51.35 | 52.60 |
| | | Cooling | 0.36 | 0.84 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.26 |
| | M5 | Heating | 0.87 | 0.94 | 1.75 | 3.84 | 5.32 | 6.70 | 7.60 | 6.44 | 5.38 | 3.79 | 2.91 | 1.62 | 47.16 | 48.82 |
| | | Cooling | 0.51 | 0.96 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 1.66 |

*S = solution; M = model; H = heating; C = cooling.*
### Table A3. Energy demand—Valdivia.

| S  | M   | H/C | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | H/C | Total |
|----|-----|-----|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| M1 | Heating | 6.08 | 5.93 | 9.55 | 15.29 | 21.17 | 24.95 | 27.41 | 23.60 | 19.14 | 14.45 | 11.12 | 7.76 | 186.45 |
|    | Cooling | 4.19 | 4.74 | 1.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M2 | Heating | 4.01 | 3.73 | 6.20 | 10.16 | 14.18 | 16.94 | 18.71 | 16.09 | 13.03 | 9.76 | 7.53 | 5.16 | 125.51 |
|    | Cooling | 2.45 | 2.75 | 0.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| S1 | M3 | Heating | 2.92 | 2.66 | 4.69 | 7.81 | 10.95 | 13.23 | 14.68 | 12.62 | 10.22 | 7.62 | 5.88 | 3.92 | 97.21 |
|    | Cooling | 1.67 | 1.96 | 0.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M4 | Heating | 2.24 | 2.31 | 4.29 | 7.37 | 10.32 | 12.48 | 13.87 | 11.92 | 9.67 | 7.20 | 5.55 | 3.45 | 90.69 |
|    | Cooling | 0.38 | 1.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M5 | Heating | 1.65 | 1.67 | 3.32 | 5.84 | 8.22 | 10.07 | 11.24 | 9.65 | 7.82 | 5.77 | 4.45 | 2.65 | 72.33 |
|    | Cooling | 0.65 | 1.19 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| S2 | M1 | Heating | 3.11 | 2.99 | 4.95 | 8.06 | 11.38 | 13.62 | 14.98 | 12.87 | 10.35 | 7.67 | 5.90 | 4.02 | 99.90 |
|    | Cooling | 1.30 | 2.31 | 0.28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M2 | Heating | 2.18 | 1.98 | 3.51 | 5.89 | 8.36 | 10.25 | 11.38 | 9.75 | 7.84 | 5.77 | 4.46 | 2.94 | 74.32 |
|    | Cooling | 0.64 | 1.27 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M3 | Heating | 1.60 | 1.56 | 2.81 | 4.89 | 6.97 | 8.66 | 9.67 | 8.28 | 6.68 | 4.88 | 3.78 | 2.32 | 62.11 |
|    | Cooling | 0.57 | 1.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M4 | Heating | 1.19 | 1.29 | 2.62 | 4.72 | 6.75 | 8.37 | 9.34 | 7.99 | 6.41 | 4.67 | 3.60 | 2.05 | 58.99 |
|    | Cooling | 0.18 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M5 | Heating | 1.00 | 1.03 | 2.22 | 4.20 | 6.01 | 7.53 | 8.43 | 7.21 | 5.80 | 4.20 | 3.21 | 1.81 | 52.65 |
|    | Cooling | 0.48 | 0.96 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| S3 | M1 | Heating | 2.57 | 2.44 | 4.07 | 6.72 | 9.56 | 11.55 | 12.71 | 10.91 | 8.75 | 6.44 | 4.96 | 3.34 | 84.02 |
|    | Cooling | 1.32 | 2.03 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M2 | Heating | 1.75 | 1.69 | 3.01 | 5.18 | 7.39 | 9.12 | 10.15 | 8.70 | 6.99 | 5.12 | 3.96 | 2.49 | 65.53 |
|    | Cooling | 0.83 | 1.20 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M3 | Heating | 1.32 | 1.32 | 2.54 | 4.51 | 6.44 | 8.04 | 8.99 | 7.70 | 6.21 | 4.53 | 3.51 | 2.02 | 57.11 |
|    | Cooling | 0.75 | 0.97 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M4 | Heating | 0.92 | 0.98 | 2.25 | 4.27 | 6.13 | 7.66 | 8.56 | 7.31 | 5.86 | 4.25 | 3.25 | 1.82 | 53.27 |
|    | Cooling | 0.37 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| M5 | Heating | 0.84 | 0.85 | 1.99 | 3.93 | 5.64 | 7.10 | 7.97 | 6.80 | 5.47 | 3.95 | 3.01 | 1.69 | 49.22 |
|    | Cooling | 0.68 | 0.98 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

S = solution; M = model; H = heating; C = cooling.
### Table A4. Energy demand—Puerto Montt.

| S | M | H/C | Monthly Energy Demand [kWh/m²] | Annual Energy Demand [kWh/m²] |
|---|---|-----|---------------------------------|-------------------------------|
|   |   | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | H/C | Total |
| S1 | M1 | Heating | 7.11 | 7.06 | 11.37 | 16.92 | 22.88 | 27.66 | 29.23 | 26.72 | 22.28 | 17.13 | 13.66 | 9.45 | 211.46 |
|    | Cooling | 0.06 | 0.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 211.91 |
|    | M2 | Heating | 4.71 | 4.66 | 7.52 | 11.40 | 15.62 | 19.05 | 20.19 | 18.57 | 15.44 | 11.83 | 9.38 | 6.35 | 144.71 |
|    | Cooling | 0.00 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 144.93 |
|    | M3 | Heating | 3.63 | 3.56 | 5.77 | 8.88 | 12.28 | 15.06 | 16.01 | 14.82 | 12.30 | 9.43 | 7.43 | 4.93 | 114.09 |
|    | Cooling | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 114.25 |
|    | M4 | Heating | 3.36 | 3.18 | 5.42 | 8.38 | 11.58 | 14.19 | 15.11 | 14.01 | 11.65 | 8.93 | 7.03 | 4.64 | 107.49 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 107.49 |
|    | M5 | Heating | 2.58 | 2.42 | 4.24 | 6.72 | 9.38 | 11.60 | 12.37 | 11.55 | 9.56 | 7.31 | 5.72 | 3.69 | 87.13 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 87.17 |
|   | M1 | Heating | 3.65 | 3.63 | 5.88 | 9.06 | 12.45 | 15.49 | 16.30 | 14.95 | 12.26 | 9.23 | 7.30 | 4.90 | 115.09 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 115.09 |
|    | M2 | Heating | 2.65 | 2.64 | 4.29 | 6.77 | 9.47 | 11.85 | 12.56 | 11.66 | 9.61 | 7.27 | 5.69 | 3.68 | 88.13 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 88.13 |
|    | M3 | Heating | 2.19 | 2.14 | 3.55 | 5.71 | 8.07 | 10.13 | 10.79 | 10.11 | 8.31 | 6.31 | 4.90 | 3.10 | 75.33 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 75.33 |
|    | M4 | Heating | 1.98 | 1.90 | 3.38 | 5.47 | 7.74 | 9.78 | 10.40 | 9.69 | 7.95 | 5.97 | 4.64 | 2.93 | 71.84 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 71.84 |
|    | M5 | Heating | 1.70 | 1.61 | 2.94 | 4.92 | 7.00 | 8.87 | 9.46 | 8.87 | 7.26 | 5.48 | 4.24 | 2.58 | 64.92 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 64.92 |
| S2 | M1 | Heating | 3.01 | 3.01 | 4.88 | 7.62 | 10.55 | 13.26 | 13.94 | 12.82 | 10.47 | 7.84 | 6.18 | 4.08 | 97.67 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 97.67 |
|    | M2 | Heating | 2.31 | 2.29 | 3.75 | 5.99 | 8.45 | 10.64 | 11.29 | 10.51 | 8.64 | 6.52 | 5.08 | 3.24 | 78.72 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 78.72 |
|    | M3 | Heating | 1.98 | 1.90 | 3.24 | 5.29 | 7.51 | 9.46 | 10.08 | 9.48 | 7.78 | 5.90 | 4.58 | 2.87 | 70.08 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 70.08 |
|    | M4 | Heating | 1.71 | 1.61 | 2.97 | 4.98 | 7.10 | 9.01 | 9.59 | 8.96 | 7.33 | 5.50 | 4.26 | 2.59 | 65.62 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 65.62 |
|    | M5 | Heating | 1.47 | 1.47 | 2.66 | 4.63 | 6.62 | 8.40 | 8.97 | 8.43 | 6.90 | 5.20 | 4.01 | 2.30 | 61.06 |
|    | Cooling | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 61.06 |

S = solution; M = model; H = heating; C = cooling.
### Table A5. Energy demand—Coyhaique.

| S | M | H/C | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | H/C | Total |
|---|---|-----|------|------|------|------|-----|------|------|------|------|------|------|------|-----|-------|
| **S1** | M1 | Heating | 3.57 | 4.50 | 7.70 | 15.05 | 27.17 | 33.15 | 37.66 | 29.82 | 22.12 | 14.53 | 10.14 | 5.41 | 210.82 |
| | Cooling | 6.51 | 6.79 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 2.98 | 17.30 | 228.12 |
| | M2 | Heating | 2.22 | 2.98 | 5.23 | 10.38 | 18.99 | 23.41 | 26.63 | 21.23 | 15.85 | 10.30 | 7.18 | 3.68 | 148.08 |
| | Cooling | 4.26 | 4.29 | 0.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.88 | 11.04 |
| | M3 | Heating | 1.64 | 2.26 | 4.11 | 8.27 | 15.23 | 18.90 | 21.53 | 17.30 | 13.03 | 8.40 | 5.88 | 2.87 | 119.40 |
| | Cooling | 3.19 | 3.24 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 | 8.29 |
| | M4 | Heating | 1.41 | 1.99 | 3.66 | 7.77 | 14.34 | 17.81 | 20.33 | 16.35 | 12.33 | 7.93 | 5.49 | 2.54 | 111.95 |
| | Cooling | 2.42 | 2.64 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.98 | 6.31 |
| | M5 | Heating | 1.12 | 1.60 | 2.92 | 6.37 | 11.88 | 14.87 | 17.01 | 13.72 | 10.42 | 6.65 | 4.60 | 2.02 | 93.18 |
| | Cooling | 2.12 | 2.27 | 0.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.90 | 5.65 |
| **S2** | M1 | Heating | 1.78 | 2.45 | 4.20 | 8.44 | 15.64 | 19.26 | 21.93 | 17.15 | 12.72 | 8.21 | 5.75 | 2.92 | 120.45 |
| | Cooling | 3.93 | 4.12 | 0.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.57 | 10.05 |
| | M2 | Heating | 1.28 | 1.78 | 3.17 | 6.48 | 12.16 | 15.21 | 17.35 | 13.87 | 10.44 | 6.64 | 4.67 | 2.19 | 95.22 |
| | Cooling | 2.37 | 2.46 | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.91 | 6.06 |
| | M3 | Heating | 1.03 | 1.52 | 2.67 | 5.60 | 10.55 | 13.28 | 15.19 | 12.25 | 9.33 | 5.91 | 4.15 | 1.86 | 83.35 |
| | Cooling | 1.86 | 2.02 | 0.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.74 | 4.90 |
| | M4 | Heating | 0.88 | 1.30 | 2.32 | 5.31 | 10.14 | 12.78 | 14.62 | 11.70 | 8.83 | 5.55 | 3.83 | 1.59 | 78.85 |
| | Cooling | 1.82 | 2.07 | 0.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.79 | 5.00 |
| | M5 | Heating | 0.78 | 1.20 | 2.09 | 4.83 | 9.29 | 11.75 | 13.48 | 10.84 | 8.25 | 5.18 | 3.57 | 1.43 | 72.68 |
| | Cooling | 1.85 | 1.84 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 4.73 |
| **S3** | M1 | Heating | 1.48 | 2.06 | 3.56 | 7.22 | 13.50 | 16.74 | 19.07 | 14.92 | 11.07 | 7.09 | 4.97 | 2.42 | 104.10 |
| | Cooling | 3.48 | 3.56 | 0.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.40 | 8.87 |
| | M2 | Heating | 1.08 | 1.60 | 2.80 | 5.83 | 11.02 | 13.84 | 15.80 | 12.65 | 9.55 | 6.05 | 4.25 | 1.96 | 86.43 |
| | Cooling | 2.26 | 2.28 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.85 | 5.70 |
| | M3 | Heating | 0.93 | 1.35 | 2.40 | 5.25 | 9.92 | 12.52 | 14.33 | 11.57 | 8.85 | 5.60 | 3.93 | 1.66 | 78.32 |
| | Cooling | 1.86 | 1.96 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.73 | 4.85 |
| | M4 | Heating | 0.77 | 1.18 | 2.08 | 4.88 | 9.41 | 11.91 | 13.64 | 10.92 | 8.27 | 5.18 | 3.53 | 1.39 | 73.18 |
| | Cooling | 1.87 | 1.94 | 0.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.73 | 4.90 |
| | M5 | Heating | 0.71 | 1.12 | 1.89 | 4.57 | 8.85 | 11.23 | 12.89 | 10.38 | 7.92 | 4.95 | 3.36 | 1.30 | 69.18 |
| | Cooling | 1.82 | 1.81 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.68 | 4.65 |

S = solution; M = model; H = heating; C = cooling.
### Table A6. Energy demand—Punta Arenas.

| S  | M | H/C | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | H/C Total |
|----|---|-----|------|------|------|------|-----|------|------|------|------|------|------|------|----------|
| S1 | M1 | Heating | 14.15 | 13.53 | 21.10 | 29.19 | 39.38 | 46.34 | 48.17 | 42.56 | 32.21 | 26.08 | 20.01 | 14.25 | 346.98  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M2 | Heating | 10.39 | 9.72  | 15.10 | 20.85 | 27.99 | 32.80 | 34.20 | 30.59 | 23.59 | 19.40 | 15.13 | 10.57 | 250.33  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | S2 | Heating | 8.75  | 8.03  | 12.44 | 17.02 | 22.71 | 26.50 | 27.70 | 25.07 | 19.66 | 16.43 | 13.02 | 9.03  | 206.38  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | S3 | Heating | 8.28  | 7.59  | 11.77 | 16.06 | 21.42 | 25.00 | 26.15 | 23.69 | 18.64 | 15.66 | 12.44 | 8.62  | 195.31  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M4 | Heating | 7.13  | 6.44  | 9.97  | 13.54 | 17.97 | 20.95 | 21.95 | 20.04 | 15.93 | 13.59 | 10.93 | 7.54  | 165.98  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M5 | Heating | 6.99  | 6.40  | 9.96  | 13.76 | 18.39 | 21.55 | 22.51 | 20.41 | 15.97 | 13.43 | 10.64 | 7.23  | 167.25  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | S4 | Heating | 6.45  | 5.78  | 8.96  | 12.18 | 16.13 | 18.81 | 19.70 | 18.09 | 14.42 | 12.42 | 10.03 | 6.87  | 149.84  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M4 | Heating | 5.96  | 5.39  | 8.42  | 11.62 | 15.53 | 18.22 | 19.06 | 17.37 | 13.68 | 11.60 | 9.26  | 6.25  | 142.36  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M5 | Heating | 5.70  | 5.08  | 7.91  | 10.79 | 14.33 | 16.76 | 17.56 | 16.14 | 12.87 | 11.10 | 8.98  | 6.10  | 133.31  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | S5 | Heating | 7.06  | 6.67  | 10.53 | 14.89 | 20.18 | 23.98 | 24.88 | 22.07 | 16.53 | 13.46 | 10.31 | 7.09  | 177.66  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M4 | Heating | 6.46  | 5.87  | 9.13  | 12.58 | 16.79 | 19.67 | 20.56 | 18.72 | 14.73 | 12.48 | 9.95  | 6.74  | 153.67  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M5 | Heating | 6.18  | 5.50  | 8.51  | 11.53 | 15.24 | 17.77 | 18.62 | 17.15 | 13.73 | 11.91 | 9.68  | 6.63  | 142.43  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M5 | Heating | 5.63  | 5.06  | 7.91  | 10.88 | 14.51 | 17.01 | 17.81 | 16.30 | 12.89 | 11.02 | 8.84  | 5.96  | 133.83  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |
|    | M5 | Heating | 5.52  | 4.89  | 7.60  | 10.35 | 13.72 | 16.03 | 16.81 | 15.49 | 12.39 | 10.76 | 8.74  | 5.94  | 128.23  |
|    |   | Cooling | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00     |

S = solution; M = model; H = heating; C = cooling.
References

1. Chile Plan de Acción de Eficiencia Energética 2020, Ministerio de Energía; Santiago de Chile. 2013. Available online: https://www.amchamchile.cl/UserFiles/Image/Events/octubre/energia/plan-de-accion-de-eficiencia-energetica2020.pdf (accessed on 10 June 2021).

2. International Energy Agency. World Energy Investment Outlook; International Energy Agency: Paris, France, 2021; Volume 23.

3. United Nations. Kyoto protocol to the United Nations Framework Convention on Climate Change; United Nations: New York, NY, USA, 1997.

4. ISO 52016-1:2017–Energy Performance of Buildings–Energy Needs for Heating and Cooling, Internal Temperatures and Sensible and Latent Heat Loads–Part 1: Calculation Procedures. Available online: https://www.iso.org/standard/65696.html (accessed on 30 June 2021).

5. Bustamante, W.; Cepeda, R.; Martinez, P.; Santa Maria, H. Eficiencia energética en vivienda social: Un desafío posible. In Camino Al Bicentenario: Propuestas Para Chile; Concurso Políticas Públicas: Santiago, Chile, 2009; pp. 253–283. ISBN 9789561413931.

6. Givoni, B. Conservation and the use of integrated-passive energy systems in architecture. Energy Build. 1981, 3, 213–227. [CrossRef]

7. Parasonis, J.; Keizikas, A.; Kalibatiene, D. The relationship between the shape of a building and its energy performance. Arch. Eng. Des. Manag. 2012, 8, 246–256. [CrossRef]

8. Parasonis, J.; Keizikas, A. Possibilities to Reduce the Energy Demand for Multistory Residential Buildings. In Proceedings of the 10th International Conference, Vilnius, Lithuania, 19–21 May 2010; pp. 989–993.

9. Carpio, M.; Jódar, J.; Rodríguez, M.L.; Zamorano, M. A proposed method based on approximation and interpolation for determining climatic zones and its effect on energy demand and CO2 emissions from buildings. Energy Build. 2015, 87, 253–264. [CrossRef]

10. Verichev, K.; Zamorano, M.; Fuentes-Sepúlveda, A.; Cárdenas, N.; Carpio, M. Adaptation and mitigation to climate change of envelope wall thermal insulation of residential buildings in a temperate oceanic climate. Energy Build. 2021, 235, 110719. [CrossRef]

11. Parasonis, J.; Keizikas, A.; Endriukaitytė, A.; Kalibatiene, D. Architectural Solutions to Increase the Energy Efficiency of Buildings. J. Civ. Eng. Manag. 2012, 18, 71–80. [CrossRef]

12. Aksoy, U.T.; Inall, M. Impacts of some building passive design parameters on heating demand for a cold region. Build. Environ. 2006, 41, 1742–1754. [CrossRef]

13. Depecker, P.; Menezo, C.; Virgone, J.; Lepers, S. Design of buildings shape and energetic consumption. Build. Environ. 2001, 36, 627–635. [CrossRef]

14. Danielski, I.; Fröling, M.; Joelsson, A. The Impact of the Shape Factor on Final Energy Demand in Residential Buildings in Nordic Climates. In Proceedings of the World Renewable Energy Forum, Denver, CO, USA, 13–17 May 2012; Volume 7.

15. Carpio, M.; Garcia-Maraver, A.; Ruiz, D.P.; Martin-Morales, M. Impact of the envelope design of residential buildings on their acclimation energy demand, CO2 emissions and energy rating. WIT Trans. Ecol. Environ. 2014, 186, 387–398. [CrossRef]

16. Sarricolea, P.; Herrera-Ossandon, M.; Meseguer-Ruiz, Ó. Climatic regionalisation of continental Chile. J. Maps 2017, 13, 66–73. [CrossRef]

17. Comisión Nacional de Energía Balancetaria–Chile. Available online: https://www.cne.cl/ (accessed on 30 July 2021).

18. Marcos Martín, F. Biocombustibles Sólidos de Origen Forestal; AENOR: Madrid, Spain, 2001; ISBN 9788481432725.

19. Carpio, M.; Zamorano, M.; Costa, M. Impact of using biomass boilers on the energy rating and CO2 emissions of Iberian Peninsula residential buildings. Energy Build. 2013, 66, 732–744. [CrossRef]

20. Chile Ordenanza General de Urbanismo y Construcciones (OGUC); Ministerio de Vivienda y Urbanismo: Santiago, Chile, 2009.

21. Verichev, K.; Carpio, M. Climatic zoning for building construction in a temperate climate of Chile. Sustain. Cities Soc. 2018, 40, 352–364. [CrossRef]

22. Verichev, K.; Zamorano, M.; Carpio, M. Assessing the applicability of various climatic zoning methods for building construction: Case study from the extreme southern part of Chile. Build. Environ. 2019, 160, 106165. [CrossRef]

23. Verichev, K.; Zamorano, M.; Carpio, M. Effects of climate change on variations in climatic zones and heating energy consumption of residential buildings in the southern Chile. Energy Build. 2020, 215, 109874. [CrossRef]

24. Prieto, A.J.; Verichev, K.; Carpio, M. Heritage, resilience and climate change: A fuzzy logic application in timber-framed masonry buildings in Valparaíso, Chile. Build. Environ. 2020, 174, 106657. [CrossRef]

25. Agencia Chilena de Eficiencia Energética. Manual de Gestion Energetico–Sector Construccion 2014. p. 252. Available online: http://old.acee.cl/eficiencia-energetica/guia (accessed on 10 June 2021).

26. Agencia Chilena De Eficiencia Energética. Guía De Diseño Para La Eficiencia Energética En La Vivienda Social 2009; Agencia Chilena De Eficiencia Energética: Santiago, Chile, 2009; p. 203.

27. Meteostat Meteonorm 7 2019. Available online: http://old.acee.cl/576/articles-61341_doc_pdf.pdf (accessed on 10 June 2021).

28. Chile Factores de Emisión, Ministerio de Energía. Available online: https://www.energia.gob.cl/ (accessed on 30 July 2021).

29. Spain Plan de Energías Renovables 2011–2020. Ministerio de Industria, Turismo y Comercio Gobierno de España, IDEA. 2011; pp. 1–824. Available online: https://www.miteco.gob.es/es/cambio-climatico/legislacion/documentacion/PER_2011-2020_VOL_1_tcm30-178649.pdf (accessed on 10 June 2021).
30. Comisión Nacional de Energía Anuario Estadístico de Energía 2005–2015. 2015. Available online: https://www.cne.cl/wp-content/uploads/2016/07/AnuarioCNE2015_vFinal-Castellano.pdf (accessed on 10 June 2021).
31. Romero, J. Cuantificación, Caracterización Y Análisis De La Comercialización De Leña En Puerto Williams, Isla Navarino, XII Region. 2007. Available online: http://dspace.utalca.cl/handle/1950/6251 (accessed on 10 June 2021).
32. CDT Medición del Consumo Nacional de Leña y Otros Combustibles Sólidos Derivados de la Madera; Ministerio de Energía: Santiago, Chile, 2015.
33. Instituto para la Diversificación y Ahorro de la Energía IDEA. Available online: http://www.idae.es/ (accessed on 30 July 2021).
34. Autodesk Autodesk. Available online: https://www.autodesk.com/ (accessed on 30 July 2021).
35. ISO ISO 52017-1:2017–Energy Performance of Buildings–Sensible and Latent Heat Loads and Internal Temperatures–Part 1: Generic Calculation Procedures. Available online: https://www.iso.org/standard/65698.html (accessed on 30 June 2017).
36. ISO ISO 13789:2017–Thermal Performance of Buildings–Transmission and Ventilation Heat Transfer Coefficients–Calculation Method. Available online: https://www.iso.org/standard/65713.html (accessed on 30 June 2017).
37. Albatici, R.; Passerini, F. Building Shape and Heating Requirements: A Parametric Approach Italian Climatic Conditions. In Proceedings of the CESB–Central Europe towards Sustainable Building Conference, Prague, Czech Republic, 30 June–2 July 2010.
38. Vásquez, C.; Encinas, F.; D’Alençon, R. Edificios de oficinas en Santiago: ¿Qué estamos haciendo desde el punto de vista del consumo energético? Arq 2015, 89, 50–61. [CrossRef]