Breakdown of the Use of Energy in Common Areas of Residential Buildings in Chile

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Abstract. In the last 15 years the population of the Metropolitan Region has increased by 16.10%. Due to this greater densification, many people have had to live in residential buildings. By accepting this condition, residents have also accepted a monthly payment of common expenses. The reality shows that the latter are unpredictable prior to the operation of the building and once in operation their distribution and origin, allowing for the planning of resources, is not known. Based on the foregoing, we propose an energy calculation method to estimate the electricity and gas consumption of hot water for both domestic use and heating of the facilities present in the common areas of buildings. The method was applied in 2 residential buildings in Santiago with similar characteristics in order to compare the results obtained with the calculation method versus the actual consumption information. The results show that the most consumed basic services correspond to gas used for boilers at 67.5% and electricity at 29%. Regarding electricity, cold water pumps generated the highest energy consumption followed by lighting of parking areas. The percentage difference between the estimated monthly expenditure and the monthly expense charged for electricity was 11.50% and 9.19% for Building A and B, respectively. Moreover, in the case of gas, the difference was 21.10% for Building A and 17.09% for Building B.

1. Introduction

In the last 15 years in Chile, specifically the Metropolitan Region, there has been a considerable increase in population, increasing by 975,607 inhabitants, which is 16.10% more than in 2002[1]. Due to this high densification many people live in residential buildings, which is reflected in the number of square meters of apartments built nationwide and in the Metropolitan Region. In the last 3 years they have reached average values of 6,664,205m² and 4,265,811m², respectively [2]. Moreover, the scarcity of land available, the dangers of buying land, the difficulty in building a home and the high price of land are some of the main reasons for buying an apartment [3].

However, when choosing the option of living in a residential building, what all its owners or tenants have in common is that they must face the payment of common expenses. The common expense is the money that building administrations use for the payment of the basic and personal services of a building.
so that it can function correctly. The problem that currently arises is that within the country there is a considerable variation in the common expenses according to the commune or city in which the building is located. The complication is that in the literature there is no detailed information that allows to analyze the differences of common expenses between one building and another, nor the behavior of the distribution of common expenses.

On the other hand, from an energy point of view, the residential sector represents 15.4% of energy consumption at the national level, thus it is essential to understand what the origins of this consumption are as well as to determine which facilities represent the highest consumption.

Finch et al. [5] conducted a study regarding the energy consumption of 39 residential buildings of medium and high altitude in Canada. These buildings used a combination of natural gas and electric power, which were measured for each home and all common areas. The researchers concluded that of the total energy consumed 49% corresponds to electricity and 51% to natural gas. 37% of the total energy of the building is used for heating spaces, of which 69% of the thermal energy for heating comes from gas.

In this study the electricity for common areas considered rooftop facilities, elevators, swimming pool, parking areas, recreation areas and parking spaces. No information is mentioned to quantify the energy consumption of pumps. However, there are regulations such as EN15316-2-3[6], NCh2485[7] and NCh2794[8] that allow to calculate the energy consumption of pumps.

Regarding the consumption of gas given by the consumption of Domestic Hot Water (DHW) and Space Heating Water (SHW), currently in the European Union there is a Manual [9] that establishes the guidelines for the allocation of the costs and billing of individual energy consumption for heating, refrigeration and DHW. But each member state of the European Union can consider certain criteria in its application.

In Chile, new residential buildings are usually equipped with water meters to measure individual consumption of DHW and SHW. As Figure 1 shows, the most common way to charge energy costs is to allocate fixed percentages (50%) per apartment living area for individual consumption of DHW (25% in heating season, 50% the rest of the year) and for individual consumption of SHW (25% in heating season). The flaw of this allocation method is that it does not consider the real energy consumption in DHW and SHW, which can produce deviations in the allocation of expenses, especially in transitory periods.

**Figure 1.** Allocation of energy costs most commonly used in Chile

The objective of the present study is to estimate the breakdown of energy consumption of installations in the common areas of residential buildings. With this we seek to mainly solve two
problems: 1) to estimate the common expenses of new buildings for future owners before carrying out
construction, and therefore sales, since this could mean a competitive advantage on the part of real estate
that could influence buyers in their purchase decision, and 2) to plan the maintenance and rehabilitation
of the equipment installed in common areas in existing buildings, since the Chilean Law N°19.537 [10]
does not provide information regarding the possibility of requesting loans, thus planning must be made
to gather the necessary reserve fund to carry out the maintenance

2. Energy calculation method

To perform the theoretical calculation of electricity and gas consumption, first we carried out a field
visit, which consisted of reviewing and collecting information on the facilities of each of the premises
in the common areas of the building. These enclosures included: reception, corridors, emergency stairs,
gym, garbage room, multipurpose room, parking, storage room, cold water pump room, boiler room,
elevators, rooftop, laundry, barbecue area, pool and any other venue considered to be for common use.

2.1. Calculation of electricity

During the field visit, we collected information on the facilities that consume electricity in the common
areas of the building. These included: luminaires, elevators, heating pumps, accumulation pumps,
recirculation pumps, cold water pumps and domestic appliances such as washing machines and dryers.

2.1.1. Lighting and equipment.

The calculation of the energy expenditure of the lighting and equipment of an enclosure is given by the
type of luminaire or equipment used, the amount, the monthly time of use and the value of the electricity
per kWh (Equation 1).

\[ G_{el} = C \times P \times t \times m_e \]  

Where \( G_{el} \) is the energy expenditure of the lighting or equipment of an enclosure, \( C \) is the number of
luminaires or equipment of the same type, \( P \) is the power of the luminaire or equipment, \( t \) is the monthly
usage time (in hours) and \( m_e \) is the price of electricity.

On the other hand, the time of monthly use of each of the luminaires was considered according to
the information delivered in situ. In the case of washing machines and dryers it was calculated based on
the amount of chips used monthly.

2.1.2. Elevators.

To calculate the energy consumption of the elevators, it was necessary to initially collect information
on the quantity, elevator model and luminaires installed inside the cabin. We can use a common
methodology VDI4707 [11], which may present slight modifications according to the information
available on the technical characteristics of the elevator.

2.1.3. Pumps.

To calculate the energy consumption of the pumps, information must first be gathered from the pumps
installed in the building. These can include: DHW pumps, SHW pumps, cold water pumps, pumps used
in the pool, among others. Then, for each one of the pumps the model, quantity, power and average time
of use must be recorded. When reviewing the above information, 2 cases can be presented:

Case 1: The pumps have identification plates with the technical characteristics. By having
identification plates you can directly observe the technical characteristics of the pump, such as the model
and power. With this information, in addition to the quantity and time of use, the energy consumption
of the pumps is calculated with Equation 1 as well as the lighting.

Case 2: The pumps do not have identification plates. If information on the technical characteristics
of cold water pumps is not available, NCh2485 should be used and NCh2794, which provide the
necessary information to calculate the quantity and power of the pumps to comply with building
requirements.
3. Calculation of natural/liquefied gas for thermal power

To calculate the gas energy consumption, we must consider that it is composed of two items: the gas used for the generation of sanitary hot water and the gas used for hot water for heating purposes. Here, the calculation methodology is explained in detail.

3.1. Energy demand and heating consumption

To change the parameters in a simple way during the simulation, we chose to develop a daily calculation model based on the simplified hour calculation method given by the EN-ISO13790 standard [12].

Kokogiannakis et al. [13] made a comparison between the heating and cooling demand simulated by the model of the EN-ISO13790 and the Building Performance Simulation (BPS) software ESP-r and EnergyPlus. From this they concluded that despite having a deviation with the intermittent heating, the simplified models of the EN-ISO13790 give consistent results with the results of the BPS software in terms of heating.

3.1.1. Efficiency of emission, distribution and generation.

The estimate of the additional heat required is determined monthly from the EN 15316[14]. The only difference form the models proposed the standard is the parameterized equations of pipe lengths in the recirculation circuit and of the branches proposed in the EN 15316 are not adapted to the network configuration of residential buildings, since in the case of the standard the emission devices are interconnected by vertical columns while in the case of residential buildings they are equipped with water meters, where each apartment has its own circuit that divides one or several vertical circuits of recirculation. Therefore, a parameterized model was developed where the length of the recirculation pipe is calculated in Equation 2:

\[
\begin{align*}
\text{if } N_{\text{floor}} & \leq 8 ; L_{\text{CL}} = 2 N_{\text{floor}} h_{\text{floor--ceiling}} \\
\text{else } L_{\text{CL}} &= 4 N_{\text{floor}} h_{\text{floor--ceiling}}
\end{align*}
\]

Equation 2

The individual piping of each apartment is divided into two parts: 1) the pipes from the shaft to the doors of the apartments, which depends on the number of apartments per floor and the external dimensions of the building (see Table 1), and 2) the piping within the apartment that depends on the number of bedrooms (D) and bathrooms (B) that each apartment has. The values presented in Table 2 were determined based on the study of several real estate projects.

| Apartments per floor | DHW pipe length (m) | SH pipe length (m) |
|---------------------|---------------------|--------------------|
| 2                   | (L+W)/2             | L+W                |
| 4                   | L+W                 | 2*(L+W)            |
| 6                   | 2L+3/2*W            | 4L+3W              |
| 8                   | 5/2*L+2*W           | 5L+4AW            |
Table 2. Pipe length of the heating distribution system within the apartment.

| Apartment type | DHW pipe length (m) | SH pipe length (m) |
|----------------|---------------------|--------------------|
| 1D-1B          | 11                  | 14                 |
| 2D-1B          | 16                  | 21                 |
| 2D-2B          | 18                  | 23                 |
| 3D-2B          | 24                  | 32                 |
| 4D-3B          | 40                  | 52                 |
| 4D-4B          | 49                  | 64                 |

Finally, generation losses are calculated based on the EN15316 (Equation 3):

\[ Q_{gn,SH} = Q_{gn,L,p0} + Q_{gn,Pin} \]  
Equation 3

Where the values of standby losses \( Q_{gn,L,p0} \) and of losses by intermediate load \( Q_{gn,Pin} \) are calculated by generic values tabulated in the same standard.

3.2. Energy demand and consumption of sanitary hot water

The daily energy demand for the consumption of hot water (\( Q_{DHW,nd} \)) is calculated in Equation 4:

\[ Q_{DHW,nd} = 1,16 V_{DHW} (T_{boiler, set} - T_{tw}) \]  
Equation 4

Where \( V_{DHW} \) is the daily consumption of hot water, \( T_{boiler, set} \) is the boiler set temperature and \( T_{tw} \) is the temperature of the drinking water.

According to UK Government’s Department for Environment, Food and Rural Affairs report [15] that conducted a study of hot water consumption of 120 homes, daily consumption can be estimated with the Equation 5. Where \( N \) is the number of occupants of the property:

\[ V_{DHW} = \frac{46 + 26 N}{1000} \]  
Equation 5

To verify the applicability of the equation in the Chilean context, Figure 2 shows the daily consumption of 240 apartments of 3 buildings in the metropolitan region of Santiago, Chile. Although the daily consumptions measured are very heterogeneous ranging from 26 to 801 liters per day, the averages calculated by Equation 5 agree with the averages of the measured data, presenting a difference of 6% between the calculated values and the averages of the measured values.
3.2.1. **Energy demand and consumption of domestic hot water.**
The heat losses during distribution of domestic hot water are calculated based on the same equation for heat distribution, adapting the length of pipes based on Tables 1 and 2.

### 4. Case studies

In order to protect the privacy of the buildings, these will be identified as "Building A" and "Building B". The images of the façade of both buildings are presented in Figure 3.

**Figure 2.** Consumption of DHW by type or number of bedrooms (D), estimated consumption (black solid line), average (gray dash line) and box plot of the measured data

**Figure 3.** Façade of the buildings submitted for study. Building A (left) and B (right)

Building A is located in the municipality of Providencia, Santiago. It corresponds to a single building of 7 floors and 1 underground floor of 5,828.43 m² of surface area, built in 2014. It consists of 48 apartments, whose useful area varies between 52.71 to 87.65 m². It has facilities such as: gym, event room, meeting room, laundry, playground, rooftop and green area. The type of heating used corresponds to a centralized system with a gas boiler and radiators. Regarding the lighting of the common areas of the building, the luminaires used are mainly compact fluorescent lamp, fluorescent tubes and LED.

On the other hand Building B is located in the municipality of Nuñoa, Santiago. It corresponds to a single building of 12 floors and 1 underground floor of 5,563.51 m² of surface area, built in 2004. It consists of 54 apartments, whose useful area varies between 57.03 to 90.17 m². It has facilities such as:
gym, event room, swimming pool and green areas. The type of heating used corresponds to a centralized system with a gas boiler and radiators. Regarding the lighting of the common areas of the building, the luminaires used are mainly compact fluorescent lamp, fluorescent tube and halogen.

4.1. Annual expenditure per square meters built

The annual expenditure per m$^2$ built was calculated considering the total annual expenditure for common expenses of the building divided by the square meters built. For building A, a value of $15,328 per m$^2$ and for Building B a value of $13,821 per m$^2$ was obtained.

Figure 4. Annual Distribution of Common Expenses of Building A (left) and B (right).

After the staff, basic services are the second most important item of common expenses (Figure 4), representing between 31% and 28% of the total. The basic services are divided into: electricity (30% and 28% for buildings A and B, respectively); water (2% for buildings A and B) and boiler gas (68% and 67% for buildings A and B, respectively) and exceptionally Building B also considers 30% of the water in the boiler.

5. Results and discussion

By applying the energy calculation method proposed above, we obtained the results shown in Table 3. As can be observed in the table, the estimation error of the electric consumption is very small, with a monthly difference of 11.50% and 9.19% for buildings A and B, respectively. However, a more pronounced discrepancy can be observed for gas consumption. This difference originates mainly because the tool uses average climate data from the city of Santiago.

Table 3. Comparison between the estimated monthly expenses and the charged monthly expenses for gas and electricity for Building A and Building B

| Building | Item    | Estimated monthly expenses | Charged monthly expenses | Percentage difference (%) |
|----------|---------|---------------------------|--------------------------|--------------------------|
| Building A | Gas     | $1,819,540                | $1,502,557               | 21.10%                   |
|          | Electricity | $774,155           | $694,306                 | 11.50%                   |
| Building B | Gas     | $1,404,778                | $1,199,705               | 17.09%                   |
|          | Electricity | $547,992           | $501,873                 | 9.19%                    |

Regarding electricity, it can be seen in Figure 5 that for both Building A and Building B, the highest energy consumption corresponds to lighting and pumps.
Regarding the pumps (40% and 51% of building A and B, respectively), cold water pumps have the most consumption with 80.64% of total pumps in Building A, and 79.93% of total pumps in Building B. Regarding lighting, in Building A (51%), the highest consumption occurs in underground parking lots and on the first floor, with 70.24% of the total lighting. In Building B (31%), based on the total lighting, the highest consumption occurs in underground parking and the first floor with 50.04%, and 30.82% in the lighting of the corridors.

Given the difference in gas expenses presented in Table 3 and Figure 6 compare the monthly gas consumption registered by the supply company and the consumption calculated by the calculation model of building A and B, respectively, in relation to Heating degree-days with a base temperature of 15°C. Although the model is simplified since the calculation is made with a time step of one day, the simulated results agree in a satisfactory way with the use of a preliminary energy analysis tool in a residential building.

6. Conclusion
In the present study we propose an energy calculation method that seeks to estimate both the electricity consumption and gas consumption for domestic hot water and hot water for heating in common areas of residential buildings. Subsequently, the method was applied in two residential buildings located in Santiago to analyze the behavior of each one and compare the results.

Additionally, with the information provided by the administration of the buildings it was possible to determine that of the annual distribution of common expenses, in both buildings the most relevant item corresponds to personnel with an average of 47.5%, followed by basic services with an average of 29.5%. The basic services are divided into: electricity, water and gas. The most important consumption...
occurs with gas destined for the boiler with an average of 67.5% followed by electricity with an average of 29% with respect to the total basic services.

By applying the energy method we detected that the percentage difference between the estimated expense and the expense charged for electricity was 11.5% and 9.19% for Building A and B, respectively.

Regarding the monthly distribution of electricity consumption, it was found that the highest consumption is produced by pumps with an average of 45.5%, of which 80.3% correspond to pumps for elevating cold water. The second highest consumption is by lighting, with 41%. Its greatest consumption occurs in the lighting of parking lots.

In the case of gas, the percentage difference between the estimated expense and the charged expenses reaches 21.10% and 17.09% for Building A and Building B, respectively. In both buildings there is an increase in energy consumption during the colder months, when heating is used, and a decrease in the warmer months, when heating is not necessary. The monetary difference between one building and another in the peak months is due to the number of apartments that use heating. For instance, in Building A and B, 78.7% and 20.4% of apartments use heating, respectively.

Finally, the present work not only seeks to reveal the breakdown of the use of energy in common areas of residential buildings, but also translates this into a tool that will make people in the community aware of energy consumption, allowing them to make decisions based on objective bases, leading to the implementation of measures for the benefit of lower energy consumption. In the future this could lay the foundations for the development of an energy audit in buildings.

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