Meteorological Assessment and Implementation of an Air-Side Free-Cooling System for Data Centers in Chile

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ABSTRACT

Data center energy consumption in Latin America has increased considerably during last years. According to Datacenter dynamics, energy requirements during 2016 were expected to be around 3.85 GW. In Chile, the data center industry grew 14% between 2009 and 2010, whereas energy consumption increased 21.4% between 2012 and 2013. For this reason, many data centers in the country have started to evaluate efficient alternatives to reduce energy consumption such as the use of air containment techniques, air-side and water-side cooling systems. To date, existing free-cooling maps do not provide information about available hours during the year for implementing either air-side or water-side cooling systems in data centers in South America. This paper presents a thermodynamic analysis aimed to evaluate the potential use of air-side free-cooling systems in the Chilean data center industry. First, temperature and Relative Humidity (RH) variations, during three years, were obtained at 29 different stations throughout the entire country. The objective was to identify regions in Chile that meet data center thermal requirements proposed by the ASHRAE. Fiber-optic availability was also considered during the analysis. The thermodynamic model considered a white room with a thermal load of 20 kW, for which an air treatment unit was incorporated with the objective of providing cold air at 18° and 60% RH. An air treatment system was calculated at three different locations in Chile. These locations were selected since they offer high availability of fiber-optic connections (Chacalluta, Arica y Parinacota Region), strategic position for companies (Quinta Normal, Metropolitan Region), and low temperatures through the year (Carlos Ibanez, Aysen Region). Preliminary results have demonstrated that Chile is a relatively humid country. For this reason, cooling air must be dehumidified most of the time. The results also showed that even when low temperatures can be found in Carlos Ibanez, both Chacalluta and Quinta Normal offer excellent possibilities for the data centers industry. These two last locations offer more fiber-optic connections and temperature variations that lay within the range established by the ASHRAE.

KEYWORDS: Data center, Thermal efficiency, Free-cooling.

NOMENCLATURE

h	Enthalpy, $\mathrm{kJ/(kg\,K)}$
$\dot{m}$	Mass flow rate, $\mathrm{kg/s}$
$\dot{Q}$	Heat flux, W

Greek symbols

ω	Specific humidity, kg water vapor/kg dry air

Subscripts

a	Dry air
g	Saturated water state
w	Water

INTRODUCTION

Considering that cooling represents the largest power consumer in most data centers [1], efficient thermal management practices significantly impact overall energy savings. According to the global data center census published by DCD Intelligence in 2013, the power consumption by the data center industry was around 40 GW. Chile appears as the third largest energy consumer in the South American region, with a gross electricity generation that increased 42.1% between 2005 and 2015, at an averaged 2.6% of yearly growth rate [2]. Although in recent years the country implemented aggressive policies to stimulate renewable energy sources, 59% of its electricity comes from fossil fuels [2], thus energy efficiency can have positive environmental impact in a country where a large percentage of its population struggles with air pollution.

Free cooling systems (in any of their forms) are widely used in the data center industry due to the large energy savings that they can provide compared with traditional compressor-base cooling technologies [3]. In a free cooling system, the compression refrigeration equipment (chillers or DX CRAC units) are eliminated or bypassed. In some cases, eliminating the use of compressor cooling can also eliminate the use of cooling towers, pumps and electrical gear that power them [3] providing additional energy savings. Three basic types of free cooling systems have been extensively proven in the data center industry: Air side economization, water side economization and evaporative direct or indirect cooling [3], [4]. In all cases, the external data center weather conditions restrict the amount of time in which each system can be operated. The high dependency between free cooling systems operation and weather conditions have push big data center operators to place their new data centers in zones where they can maximize the use of free cooling [4]. As part of the effort to help data center operators to make use of free cooling technology, The Green Grid have made available free cooling maps of United State, Europe and Japan [5]. These maps show historical data with the amount of hours that each geographical zone can provide per year. Digital tools for China are also available in The Green Grid website.

On the other hand, the fast grow of internet in South America and the quick adoption of new technologies of its population have put this geographical area in the eye of big data center operators. Companies like Google [6] and Amazon Web Services [7] have already see the potential of the area and have install their own data centers in Chile and Brazil respectively. The grow of the data center industry in the region make necessary to follow the path created by more developed markets and generate the conditions for data center operators to use low energy consumption technologies as free cooling.

The following paper tries to fill some of the information gap related to free cooling opportunities in South America. The work presents a preliminary study of the weather conditions in Chile and the feasibility of the use of Air side economization in different regions of the country. Variables as temperature and humidity are considered to calculate the amount of hours that each geographical area can provide.

METHODOLOGY

The number of hours available for implementing air-side free-cooling systems in Chile was calculated based on the temperature and relative humidity limits established by the ASHRAE T.C. 9.9 [8], where different environmental classes are defined for air-cooled equipment. As described in [8], class A1 represents data centers with tightly controlled environmental parameters (enterprise servers and storage products); whereas class A2, A3 and A4 represent a space with some control of environmental parameters (volume servers, storage products, personal computers, and workstations). Table 1 details the different ASHRAE standards. Temperature and relative humidity were obtained from 29 meteorological stations and considering three years of measurements (2012 to 2014) [9].

The benefits of implementing an air-side free-cooling in Chile were estimated using a room with 4 racks that dissipate a constant heat flow of 5 kW each. Heat removal is obtained by 1.51 m^3/s provided by a commercial cooling system (Ciatronic), which is described in Fig. 1. This system offers air cooling, heating, dehumidification, humidification, and it is provided with an air filter device. The system allows the use of free-cooling when ambient temperature and relative humidity range 18-22.5°C and 20-60%, respectively. If air treatment is required, the cooling system provides air at 18°C and 60%RH.

Table 1: Data center ASHRAE standards.

Class	Dry-Bulb Temperature	Humidity Range, Non-Condensing	Maximum Dew Point
Recommended	18°C - 27°C	5.5°C to 60% RH and 15°C DP	15°C
A1	15°C - 32°C	20% to 80% RH	17°C
A2	10°C - 35°C	20% to 80% RH	21°C
A3	5°C - 40°C	-12°C and 8% RH to 85% RH	24°C
A4	5°C - 45°C	-12°C and 8% RH to 90% RH	24°C

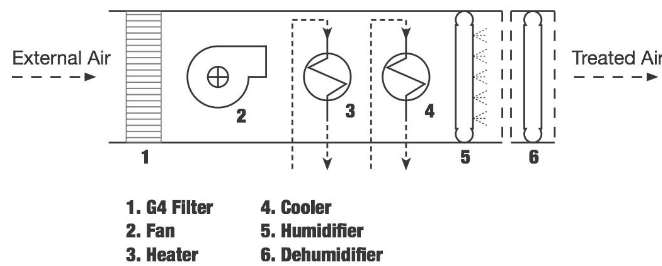

Fig. 1: Air treatment system schematic.

The thermodynamic system of equations was solved using EES (Engineering Equation Solver) [10], considering either the heating or cooling process, and also the mass transferred during either dehumidification or humidification, as follows:

Heating - Cooling:

$$\dot{Q} = \dot{m}_a(h_2 - h_1); \quad \dot{Q} = \dot{m}_a(h_1 - h_2) \tag{1}$$

Heating and humidification:

$$\dot{Q} = \dot{m}_a\left[(h_{a_2} + \omega_2 h_{g_2}) - (h_{a_1} + \omega_1 h_{g_1})\right] \tag{2}$$

Cooling and dehumidification:

$$\dot{Q} = \dot{m}_a\left(h_{a_1} - h_{a_2}\right) - \dot{m}_w h_w \tag{3}$$

The states 1 and 2 represent the location immediately before and after the heat exchanger (Heater/Cooler in Fig. 1), respectively.

RESULTS AND DISCUSSION

Territorial distribution of the free-cooling availability

Figure 2 shows the explosive increment in global internet usage between 2005 and 2015 [11]. Latin America appears as an emerging market with a significant potential for growth, in comparison to the already settled North American and European internet markets. For instance, Netflix Latin America

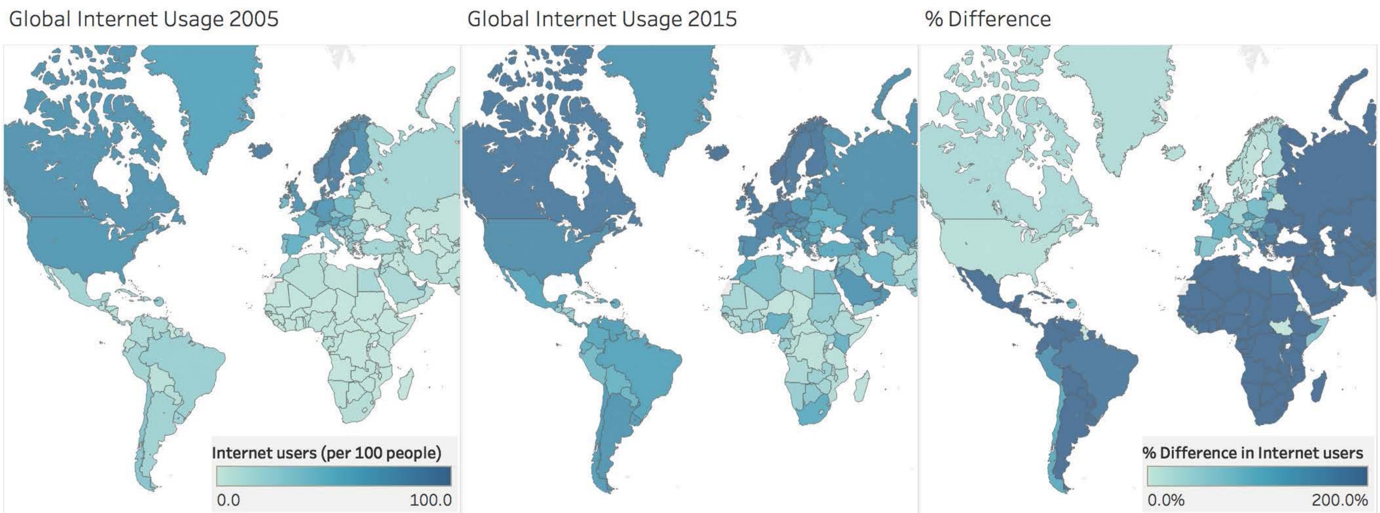

Fig. 2: Internet usage comparison per country between 2005 and 2015 and its percent difference. Some map areas are neglected for clarity.

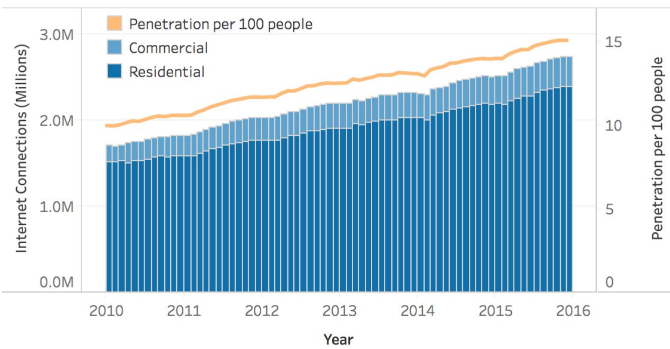

Fig. 3: Internet connections and penetration per 100 people in Chile between 2010 and 2016.

increased its subscribers from approximately 300 thousand in 2011 to more than seven million in 2015 [12].

Chile approaches levels comparable to Europe, with 64% of its population accessing internet–In Italy the internet users represent 66% of the population. Compared to the rest of Latin America, Chile grew slower (between 2005 and 2015), indicating that the country currently matures its connectivity. In fact, Google's first data center in Latin America began operating in Chile in 2015, with an investment of 150 million USD; they claim to have chosen the country thanks to its reliable infrastructure, skilled workforce and business friendly policies [13].

Residential and commercial internet connections in Chile show steady growth [14], with a slight decrease at the beginning of each year possibly due to a summer break effect (Fig. 3). Similarly, the internet penetration grew monotonically with no sign of deceleration.

The warmer and dryer weather found in the north better suits the free-cooling. Figure 4 shows the available days at the weather stations, considering the recommended range, the A1 class and the A2 class; the number of days decreases proportionally to the latitude, in other words, fewer days fall within the ASHRAE ranges at the southern stations. Let us recall that in the southern hemisphere the latitude decreases downwardly (< 0) as we move farther from the Equator.

The decrease in available days in the south is explained by two simultaneous effects: The expected decrease in the temperatures at locations closer to the Antarctic Circle, and its consequent increase in relative humidity. On the other hand, the north presents more appropriate average temperatures, with smaller fluctuations between day and night.

A notable example of availability corresponds to the northernmost location, Chacalluta. Figure 5 shows the number of days at the low and high temperatures, as well as the relative humidity in the form of histograms. In terms of the temperature range, more than 100 days fall within the recommended range, and nearly the entire year for the A1 class.

The relative humidity restrained most of the available days, with only the two leftmost bars falling within the recommended range, adding up to 33. The A1 class permits up to 80% of relative humidity, which represents the entire year and explains the large increase in available days (33 to 297) observed in Fig 4 at the Chacalluta station.

Air treatment power consumption

To evaluate the cooling performance of an air-side cooling system, the proposed system was evaluated in three different regions. The goal was to investigate the data center performance in regions with high availability of fiber optic connections (Chacalluta, Arica), industry growth (Quinta Normal, Santiago), and cold weather (Carlos Ibanez, Magallanes), considering the recommended operation range showed in Table 1.

Figure 6 shows the cooling system energy consumption at the selected locations during a typical year. In Chacalluta, the cooling process consumes more energy than the heating process (January-March) since ambient temperature is higher than 23°C most of the time. Nonetheless, heating is also required since temperature goes down to 14.8°C. On the other hand,

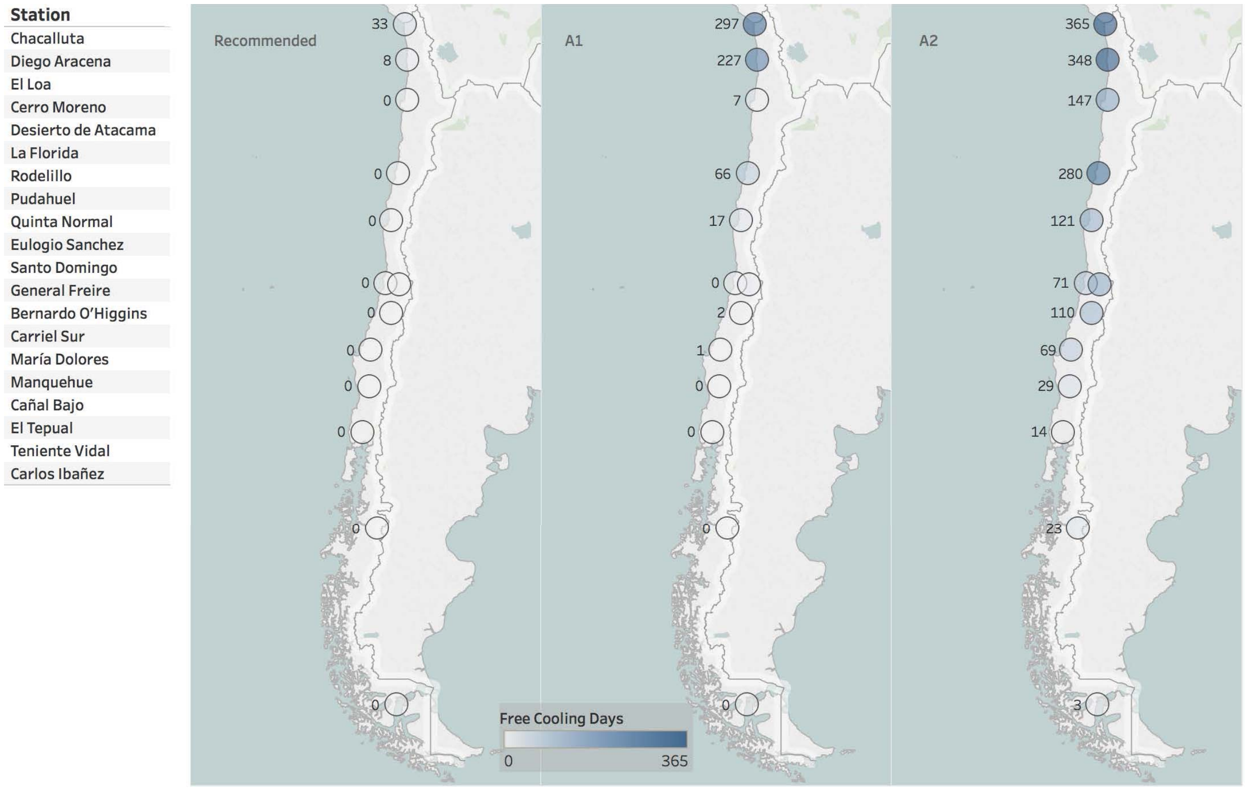

Fig. 4: Geographical distribution of the free cooling days in Chile for the three most rigorous ASHRAE standards. The station names appear sorted by latitude.

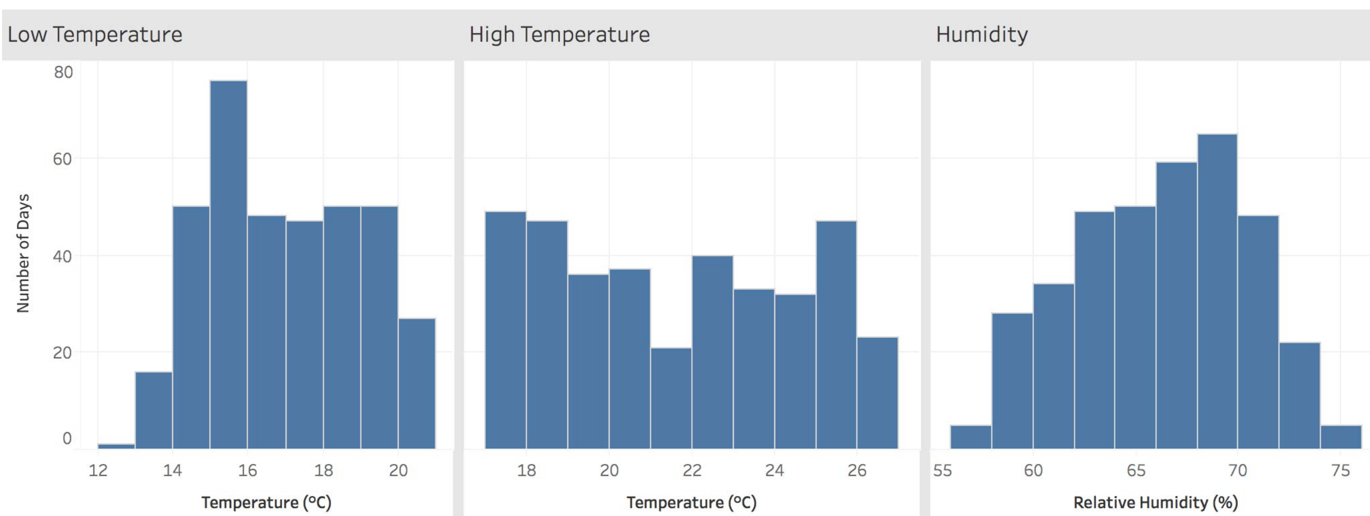

Fig. 5: Yearly distribution of Low and High temperatures, as well as relative humidity at the Chacalluta station.

from day 91 to 273 heating and dehumidification consume a significant amount of energy. Here, ambient temperature varies from 9.3 to 17.9°C, while RH varies from 62 to 76%.

In Quinta Normal (Fig. 6), from January to March, heating, cooling and humidification consume around 81% of the energy. As observed free-cooling is possible from January to April, and September to December, since temperature variation takes place between 18 and 22.5°C . Finally, in Carlos Ibanez, both heating and dehumidification consume most of the energy, since temperature varies around 11°C and RH is always higher than 60%.

CONCLUSIONS

This paper presents a preliminary evaluation of the Chilean potential for the implementation of air-side free-cooling systems in Data Centers. The analysis considers the temperature and relative humidity limits established by the ASHRAE.

The northern regions present a lower relative humidity and a smaller temperature step between day and night, which

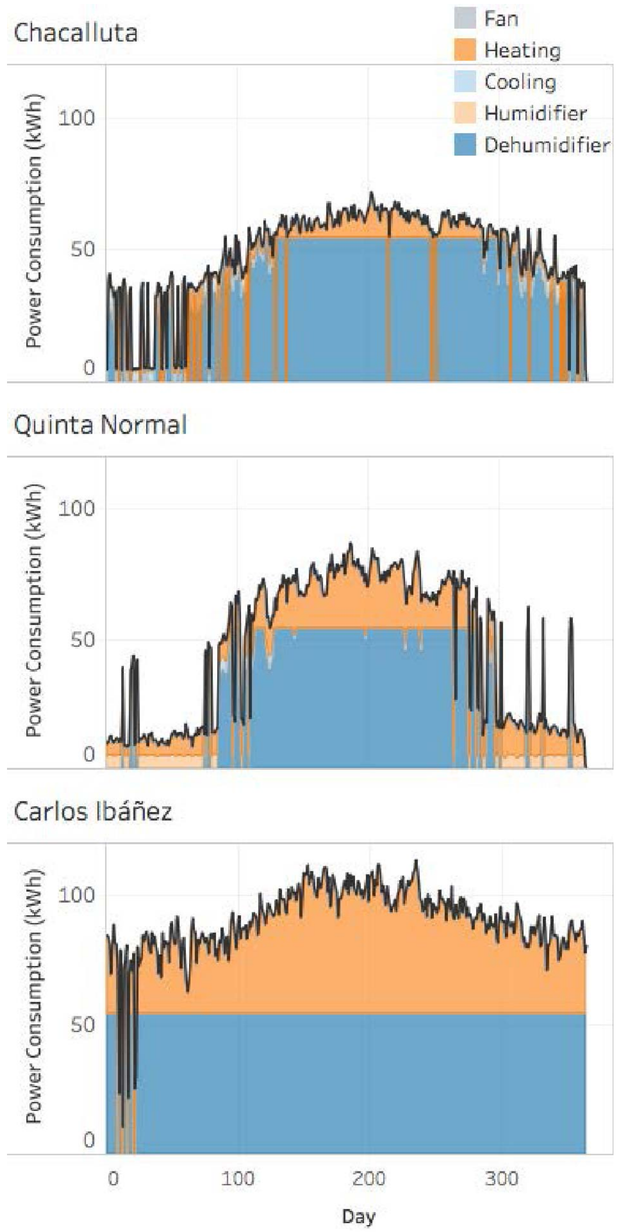

Fig. 6: Daily power consumption per air treatment throughout the year at three different stations.

manifests in more free-cooling days available. Most of the used meteorological data locate near the pacific ocean; a more complete assessment remains to be generated, especially since the inner zones present drier weather throughout, which might improve the free-cooling availability.

The proposed cooling system was evaluated at three different locations within the country: Chacalluta, Quinta Normal, and Carlos Ibanez. The thermodynamic analysis indicated that energy is mostly consumed in air heating, cooling, humidification or dehumidification. This is due to the fact that temperatures can be lower than -1°C or higher than 30°C.

Since heating and dehumidification are highly required in Carlos Ibanez, the proposed cooling systems is not suitable for the southern regions of Chile. On the other hand, since Quinta Normal offers access to fiber optic nodes, several months of free-cooling, and it is close to many data providers, it offers high possibilities for implementing air-side free-cooling systems in Chilean Data Centers.

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REFERENCES

[1] W. Van Heddeghem, S. Lambert, B. Lannoo, D. Colle, M. Pickavet, and P. Demeester, "Trends in worldwide ICT electricity consumption from 2007 to 2012," *Computer Communications*, vol. 50, pp. 64–76, 2014.

[2] N. E. Comission, "Anuario estadístico de energía 2005-2015," Energy Ministry, Chile, Tech. Rep., 2016.

[3] W. Tschudi, "Guide to minimizing compressor-based cooling in data centers," 2013.

[4] H. Zhang, S. Shao, H. Xu, H. Zou, and C. Tian, "Free cooling of data centers: A review," *Renewable and Sustainable Energy Reviews*, vol. 35, pp. 171–182, 2014.

[5] T. Harvey and J. Bean, "Updated air-side free cooling maps: The impact of ashrae 2011 allowable ranges," *The Green Grid*, 2012.

[6] [Online]. Available: https://www.google.com/about/datacenters/inside/locations/

[7] [Online]. Available: https://aws.amazon.com/about-aws/global-infrastructure/

[8] T. ASHRAE, "9.9 (2011) thermal guidelines for data processing environments–expanded datacenter classes and usage guidance," *Whitepaper prepared by ASHRAE technical committee (TC)*, vol. 9, 2011.

[9] Dirección Meteorológica de Chile, "Productos climatológicos actuales e históricos." [Online]. Available: http://164.77.222.61/climatologia/

[10] S. Klein and F. Alvarado, "Engineering equation solver," *F-Chart Software, Madison, WI*, vol. 1, 2002.

[11] [Online]. Available: http://data.worldbank.org/indicator/IT.NET.USER.P2

[12] (2016). [Online]. Available: https://www.statista.com/statistics/324452/latin-america-netflix-subscribers/

[13] (2015). [Online]. Available: https://www.google.com/about/datacenters/inside/locations/quilicura/

[14] [Online]. Available: http://www.subtel.gob.cl/estudios-y-estadisticas/internet/