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ANÁLISIS NUMÉRICO DEL DESEMPEÑO ANUAL DE ENERGÍA DE LOS EDIFICIOS DE MADERA EN CHILE

NUMERICAL ANALYSIS OF THE ANNUAL ENERGY PERFORMANCE OF TIMBER BUILDINGS IN CHILE

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Resumen

La investigación se centra en el análisis del desempeño anual de un edificio de referencia construido según los diferentes tipos de construcción: madera contralaminada, entramado liviano y mampostería. Los edificios se simulan mediante el software dinámico Trnsys en tres ciudades diferentes de Chile (Concepción, Santiago y Osorno), que se distinguen por diferentes condiciones climáticas. Los modelos dinámicos desarrollados se han afinado al desempeño energético del edificio real, ubicado en el norte de Italia. El diseño del sistema HVAC acoplado a los edificios simulados utiliza un sistema de ventilación mecánica para el cambio de aire y deshumidificación, y una bomba de calor aire-aire para la climatización de zonas térmicas. Para cada combinación de ubicación de construcción considerada en este trabajo, el rendimiento energético general se evalúa y compara entre sí, en términos de la demanda de energía neta del edificio, el consumo de energía primaria del sistema HVAC y el factor de rendimiento estacional (SPF) de la bomba de calor. El análisis muestra que, si se considera la demanda de energía de calefacción, las dos estructuras de madera se caracterizan por una solicitud de energía similar, mientras que la adopción de la estructura de mampostería determina un aumento del 26% para el consumo de energía de calefacción. El requerimiento de energía para enfriamiento está presente solo en Santiago, aunque en cantidades mínimas. Además, teniendo en cuenta la ciudad de Santiago, se ha verificado que la bomba de calor aire-aire propuesta se caracteriza por una eficiencia adecuada, tanto durante la temporada de calefacción como durante la temporada de enfriamiento: el SCOP calculado es de alrededor de 4, mientras que el valor de SEER es de aproximadamente 3.

Palabras-clave: simulaciones dinámicas, eficiencia energética, edificios de madera, recuperación activa del calor.

Abstract

The research focusses on the analysis of the annual energy performance of one reference building built according to different construction types: mass timber, timber frame and masonry. The buildings are simulated by means of the dynamic software Trnsys in three different cities of Chile (Concepción, Santiago and Osorno), distinguished by different climatic conditions. The developed dynamic models have been tuned on the energy performance of the real building, located in Northern Italy.

The design of the HVAC system coupled to the simulated buildings involves a mechanical ventilation system, used for air change and dehumidification, and an air-to-air heat pump, used for thermal zones climatization. For each combination building-location considered in this work the overall energy performance is evaluated and compared one another, in terms of building envelope net energy demand, HVAC system primary energy consumption and heat pump seasonal performance factor (SPF).

The analysis shows that, if the space heating energy demand is considered, the two wooden structures are characterized by a similar energy request, while the adoption of the masonry structure determines an increase of 26% for the heating energy consumption. The energy requirement for cooling is present only in Santiago, albeit in minimal quantities. Furthermore, taking into consideration the city of Santiago, it has been verified that the proposed air-to-air heat pump is characterized by a suitable efficiency, during both the heating and the cooling season: the calculated SCOP is around 4, while the value of SEER is approximately 3.

Keywords: dynamic simulations, energy efficiency, timber buildings, active heat recovery.

1. INTRODUCTION

The residential sector accounts for 27% of global energy consumption and 17% of CO2 emissions, playing an important role in climate change. Buildings consume electricity for lighting, domestic appliances and conditioning systems, but this still represents a small percentage of all the energy needs of the residential sector, which consists mainly of space heating, domestic hot water production, space cooling and air climatization (Payam *et al.*, 2014). The energy savings in this sector are closely linked to the insulation of the building envelope (Byrne *et al.*, 2009), through the choice of innovative construction elements combined with adequate insulation materials, in order to reduce heat losses to the environment, and to the improvement of the HVAC system, through the optimization of its performance and the use of renewable energy sources. The final objective is to obtain nZEBs, (i.e. nearly Zero Energy Buildings, (EPBD 2010/31/EU, EPBD 2018/844/EU)), characterized by almost no energy demand for heating or cooling, thanks to an optimization of the building-HVAC system coupling, the use of cutting-edge materials and construction techniques linked with in-situ renewable energy production.

Chile is moving fast towards sustainable development. The country ratified the Kyoto Protocol in August 2002, adhering to the common goal of reducing the consumption of fossil fuels, aiming to reach 20% of energy from unconventional renewables by 2025 and promoting energy production through renewable sources by 10% by 2024 (National Energy Strategy 2012-2024). The current Chilean regulation NCH 853 specifies the methodology for calculating the thermal transmittance (U-value) of opaque and transparent components that compose the building envelope. In August 2016, a preliminary project was approved with new provisions in order to provide thermo-hygrometric comfort for people, following the proposal to update thermal protection: the Article 4.1.10 of the General Ordinance on Urban Planning and Construction. In this document, *Anteproyecto de norma* (NTM 011/2 and NTM 011/3), the country is divided into 9 climate zones, from the hottest and desert areas (A) to the Antarctic glacial zones (I), and, for each zone, the requirements and certification mechanisms for the indoor air conditioning of buildings are re-established. The limits indicated by the draft standard mark a relevant improvement compared to the actual standard, but they are still quite lax compared to the limits imposed by the EU directives.

Promoting wood construction technologies can be considered interesting for a country like Chile, that counts on an extremely developed forestry sector (Tricallotis *et al.*, 2018). First, wood structure have an excellent response to seismic events and Chile is one of the areas with the greatest seismic risk in the world. The development and optimization of this type of construction is also linked to an energy efficiency perspective towards nZEBs, since wood is a renewable material with excellent insulation properties.

The present research work focusses on the analysis of the annual energy performance of three high-performance buildings that share the same geometrical features but that are designed according to different construction types, including timber construction technologies and traditional brick-concrete solutions. The energy model of each building is developed by means of the dynamic software TRNSYS (Klein *et al.*, 2010) and simulations are performed considering different cities of Chile, distinguished by different climatic conditions. Thus, the annual energy consumption of each combination building-climatic area is calculated and compared to one another.

Figure 1. South-facing facade of the reference building.

2. MATERIALS AND METHOD

2.1 Description of the reference building

The reference building considered in this paper is a recently built two-story house, located in Valenza, Northern Italy. The building is composed by two habitable floors, each corresponding to one apartment, plus a basement and a stairwell. The total net surface of the building is 297 m^2 for a total heated volume of 898 m^3. The mezzanine floor, corresponding to the first apartment, has a volume of 392 m^3 while the first floor has a variable height and has a volume of 506 m^3. The building is characterized by a high performance envelope: in fact, the U-values of opaque and transparent elements are much lower than those imposed by current Italian law (DM 26/06/2015), thanks to the wide adoption of insulating materials and an innovative construction technology.

The external walls consist of 3-layer, 0.1 m thick Cross-Laminated timber (CLT) panels, and have an outer layer of 0.16 m wood fiber insulation and an inner thin layer of insulation (0.06 m) in the counter wall. A vapor restraint layer controls the passage of humidity through the wall avoiding condensation in the layer in contact with the wood. The outer part of the basement consists of 0.30 m concrete walls and a 0.16 m layer of wood wool insulation. The roof, also made of wood, is externally formed by a covering in steel sheet followed by a waterproof membrane to avoid water infiltration. An internal layer of raw spruce planks is followed by a ventilation chamber, necessary to detach the roof covering from the insulating layer, creating a gap that allows the circulation of a homogeneous flow of air, ensuring the elimination of humidity and increasing insulation performance. Then, a rock wool insulating layer is covered by a bituminous waterproof sheet on the cavity side and followed by another vapor restraint layer. The floors are made of 5-layer 0.20 m CLT panels with a 0.1 m lightweight concrete overlay, followed by an acoustic interlayer, 0.03 m EPS insulation and a 0.06 m heavy concrete screed, with wood finishing. The interior walls are made of 2-layer plasterboard, enclosing a layer of wood fiber. Since no data on the transparent elements were available, high performance double-glazed Argon-filled windows, characterized by a U-value of 1.06 W/m^2K and a G-value of 0.586, were used.

2.2 Preliminary modelling: reference energy performance

The reference building has been modelled by means of TRNSYS. More in detail, a thermal zone for each room was simulated, in addition to one for the stairwell and one for the basement, for a total of 22 zones. The thermal capacity that the software assumes as default was increased to take into account the presence of objects and furniture.

An hourly occupation profile was simulated; for each dwelling, the occupancy varies during the day from a minimum of 0 to a maximum of 4 people, in order to consider realistic and variable internal heat gains due to building occupants. According to the international standard ISO 7730 (ISO, 2005), a heat gain of 150 W per person was introduced, equally shared between sensible and latent part; furthermore, the thermal power produced by people has been divided into the various zones proportionally to their area. For the evaluation of the sensible internal gains due to the devices, average values were obtained from the time profiles defined in the Italian standard UNI/TS 11300-1 (UNI, 2014).

A controlled mechanical ventilation (CMV) system was implemented within the model, characterized by a cross-flow heat recovery unit with a nominal efficiency equal to 90%, guaranteeing a constant air change of 0.5 vol/h. For periods in which the CMV system is not sufficient to keep the indoor humidity levels within non-dangerous values for the correct maintenance of the wooden building and the well-being of occupants, a dehumidification system is needed: for this reason, it was also implemented in the model.

In order to calculate the effective energy demand of the building, in addition to the constant air change due to the CMV, an infiltration rate of 0.1 vol/h was introduced (typical value for new buildings). Finally, internal set-point values for heating and cooling seasons were respectively fixed to 20 °C and 26 °C. The ideal energy demand of the reference building for both seasons and the design thermal/cooling load are reported in Table 1, where the energy performance indicator EP is defined as the ratio between the ideal energy demand and the net floor area of the building

Table 1: Ideal energy demand and design thermal/cooling load of the reference building.

	Energy demand (kWh/year)	Design load (kW)	EP_i (kWh/m^2year)
Heating season	5610	4.5	19
Cooling season	3608	5.9	12

3. SIMULATION RESULTS AND DISCUSSION

3.1 Analysis of the climate characteristics

Chile is characterized by the presence of extremely different climatic areas. In order to test the energy performance of timber buildings with respect to traditional buildings, three cities were taken as a reference: Santiago, Concepción and Osorno. The climatic characteristics of these locations have been analyzed, orienting the choice of the HVAC system and the refinement of the building envelope.

Santiago de Chile, the capital, is the most populated city in the country, with an average annual temperature of 14.6°C. Analyzing the temperature trend of a typical winter day for Santiago (June 15th), there is a noticeable thermal excursion during the 24 h period. The temperature range reaches 19°C, a really large value if we consider that the winter climate is generally characterized by small excursions. Similar considerations can be done for a typical summer day; analyzing the temperature trend of a typical summer day (December 14th), a significant thermal excursion also occurs between day and night - reaching 20°C. The fact that the outdoor air temperature decreases so much during the night, can be very advantageous as regards the possible exploitation of a free cooling ventilation system, which allows to lower the temperature inside the building with a really small energy consumption thanks to the introduction of fresh and properly filtered outdoor air. Furthermore, analyzing the irradiation values for Santiago, it is possible to notice that the incident radiation has interesting values also during the winter season, reaching a peak of 400 W/m^2(total irradiation on the horizontal). This represents an advantage both for the possibility of covering a large part of the winter heating energy request through the solar input and for the possible option of a photovoltaic system. Moreover, in the summer season values of 1000 W/m^2 are also reached: for the reported reasons the installation of a photovoltaic (PV) system represents a suitable solution to produce renewable electric energy.

Concepción is one of the most populated cities in Chile. Compared to Santiago's climate, in the summer season the temperatures are lower and the average annual temperature is 12.1°C. The analysis of the daily temperature trend shows, also for Concepción, the convenience to propose a system that exploits this large thermal excursion through free-cooling operation. Also in this location irradiation values are favorable for the application of a photovoltaic system.

The last city considered in this work is Osorno, which has the coldest climate among the selected locations, with an annual average temperature of 10.5°C. The daily thermal excursion is reduced compared to the previous cases: for example, in winter days, the typical temperature difference obtained along 24 hours is around 4°C. Finally, in Osorno the solar radiation is lower if compared to other cities: in winter an irradiation of 200 W/m^2 is reached, increasing to 700 W/m^2 in summer.

According to the climatic characteristics of the considered cities, the design of the building HVAC system was focused on the development of a system which uses air as thermo-vector fluid; more in detail, the plant uses the outdoor air, with no recirculation of indoor air, filters it and by means of heating/cooling coils treats the air flow in order to maintain the needed ventilation rate, ensure air renewal and guarantee proper comfort conditions within the building. Furthermore, the energy performance of the system is increased during the summer season, since according to the free-cooling operating mode takes advantage of the temperature difference between day and night, minimizing energy needs.

3.2 Re-modelling and simulation of the reference building in Chilean cities

Based on the reference building, in this work other two buildings, characterized by the same geometrical features but built by using different construction technologies, were simulated. In this way, the influence of the building envelope on the overall energy performance could be assessed. The first building resembles the reference one, made in CLT; the second one is designed in timber frame and the third one is a traditional masonry building. When changing the design from a construction system to another, minor modifications were done to the reference building in order to comply with the Chilean standards. The major differences are listed below.

Since the actual Italian law is more severe than the Chilean one, the U-value of the original CLT building envelope components is much lower than the transmittance limits reported by the Chilean standards. For the simulation in Chilean cities, however, a thinner insulation layer is proposed, in order to reduce the considerable difference between the U-values of the reference building and the limit values. For this reason, the thickness of the insulation was set at 0.12 m, compared to the 0.16 m present in the reference building, and the total thickness of the wall is reduced to 0.32 m; to conclude, the external wall transmittance is now equal to 0.173 W/m^{2}K. The requirements of the Chilean *Anteproyecto de Norma* would be complied also if the external insulation was completely removed, both because the requirements are relatively soft and because of the low thermal conductivity of wood. Nonetheless, the problem in this case would derive from the possible formation of interstitial humidity condensation, a critical point for wood structures.

The timber frame building external walls, also having a thickness of 0.32 m, are made with solid wood uprights in which wood wool insulation is inserted. The presence of the wooden studs that interrupt the insulation would determine a thermal bridge, so an additional 0.06 m wood wool layer was added. The structure is completed on both sides with 13 mm OSB panels, interposing the vapor restraint between the panel and the insulation. Immediately after the plasterboard, on the inner side, an air gap was left for the installation of the ducts, in order to avoid placing them in the frame. The resulting overall transmittance of the wall is 0.172 W/m^{2}K, the same value resulting for the external wall of the CLT building.

The masonry building was realized with 0.24 m hollow bricks. To keep the external wall thickness almost constant among all simulated buildings, the thickness of the insulation layer was reduced to 0.08 m, resulting in a total thickness of the wall of 0.34 m. In this way, the U-value of this element is slightly greater compared to the one of the two wooden buildings previously described, reaching 0.34 W/m^{2}K. While for the wooden solutions the roof was a ventilated wooden roof, in this case the roof is made of tiles and a brick-concrete layer. The same thickness of wood fiber insulation was inserted inside the roof of the wooden buildings, reaching the same U-value of 0.22 W/m^{2}K.

The three types of buildings described before were simulated in the three selected Chilean cities, for a total of 9 simulations. For each simulation, the internal heat gains due to occupants and to the devices have been modeled as for the Italian reference building. The ideal energy demand of the buildings were therefore obtained, maintaining a constant internal set-point temperature of 20°C in winter, 26°C in summer and a volumetric air change rate of 0.5 vol/h, in addition to the infiltrations considered equal to 0.1 vol/h.

Table 2: Ideal energy demand for the buildings located in the three Chilean cities.

	Space heating (kWh)			Space cooling (kWh)		
City	CLT	Frame	Masonry	CLT	Frame	Masonry
Concepción	7595	7546	10140	20	13	5
Santiago	7270	7243	9323	944	898	724
Osorno	10940	10876	14363	25	17	9

The results, presented in Table 2, show that the energy demand for space heating for masonry building is on average 25% greater than for timber buildings, independently from the location. Moreover, the energy need for heating is greater for the city of Osorno, which has the coldest climate, if compared to the other cities: in Concepción and in Santiago the ideal heating energy demand is 31% and 34% lower, respectively. Since masonry buildings are less isolated with respect to wooden ones, the energy demand for cooling is reduced. The only buildings that have a significant need for space cooling, whatever the type of construction adopted, appear to be those simulated in Santiago, which climate is characterized by external air temperatures above 26 °C for a significant part of the season.

Finally, the values of the ideal energy performance indicator for each building are shown in Table 3. The buildings in Osorno are characterized by the highest value of EP_h, while the city with the lowest heating energy demand is Concepción. It is evident that the masonry buildings generally have the larger values of EP_h: the highest EP_h is that associated to Osorno for the masonry building, reaching 48 kWh/m^{2}year. Finally, it is important to highlight that the only city that has a request for space cooling is Santiago.

Table 3: Energy performance indicators for each building in the Chilean cities.

	EP_h (kWh/m^{2}year)			EP_c (kWh/m^{2}year)		
City	CLT	Frame	Masonry	CLT	Frame	Masonry
Concepción	25	25	34	0	0	0
Santiago	24	24	31	3	3	2
Osorno	36	36	48	0	0	0

3.3 Optimization of the HVAC system

Generally, in nZEBs the building envelope components are characterized by very low values of thermal transmittance; for this reason, the building design load and, consequently, the overall energy needs for space heating/cooling significantly decrease.

As a consequence, in this kind of buildings ventilation service acquires a greater importance to ensure ideal comfort: in fact the energy requirements for the renewal of indoor air is continuously increasingly, since the hourly renewal rate to guarantee indoor air quality is relevant in well-insulated and hermetic buildings.

All these considerations led to the choice of an innovative system that combines heating, cooling and CMV in a single device to optimize the overall energy performance of the HVAC system. This device is able to guarantee the required air renewal rate and simultaneously cover the required load simply by cooling or heating the incoming air from the outside, via an air-to-air heat pump. The system can also operate in free-cooling mode during the summer season, to completely satisfy the cooling energy demand assessed in Santiago: during the night, the air flow rate is increased and the heat pump is switched off, thus exploiting for free the large daily thermal excursion.

The device proposed and simulated in this work is composed by a CMV system characterized by active heat recovery: a reversible air-to-air heat pump uses as heat source/sink the air flow entering and exiting the building, depending on the operating mode of the unit. The appliance has three operating modes:

- *Winter mode*: while the internal air (at a temperature of about 20 °C) is extracted from the conditioned zones, it is used as the heat pump heat source, flowing through the evaporation coil; then, the external air is the heat sink and it is directly heated by the condensing coil of the heat pump. The unit energy performance is extremely high since the heat source and the heat sink are characterized by high and low temperatures, respectively.
- *Summer mode*: When the machine is operating in summer mode, the cycle is reversed. The internal air, at a temperature of about 26°C, is exploited by the condensing coil as heat sink before it is expelled outdoor. Moreover, the external air is filtered, cooled and consequently dehumidified by passing through the evaporating coil before being introduced into the internal environment.
- *Free-cooling mode*: During the summer season, the building envelope tends to accumulate heat during the central hours of the day and then rejects it during the night due to the envelope thermal inertia: in these conditions the heat pump is deactivated and the device allows the introduction of external air with the simple operation of the fans (free-cooling).

The energy performance of the heat pump and of the dehumidifier has been simulated with TRNSYS for each case and compared to one another. The electrical energy absorbed by the heat pump (E_{el}) was divided into three components: the energy due only to the fans during free-cooling operation (E_{fan}), the electric energy absorbed in the heating operating mode (E_h) and the electric energy absorbed in the cooling working mode (E_c). It is important to stress that E_h and E_c take into account also the energy need for the fans during heating and cooling mode, respectively. The energy demand for cooling, divided between sensible (E_{sens}) and latent (E_{lat}), and the values of thermal energy delivered to the building (E_{th}) were also obtained, linked to the seasonal performance factor of the unit during heating and cooling seasons (SCOP and SEER, respectively). If the dehumidifier is considered, the absorbed electric energy (E_{el}), the latent (E_{lat}) and the total energy (E_{tot}) supplied by the device and the volume of condensed water were obtained.

While the detailed discussion of all obtained results is left for a future insight, it is worth noting that a reliable comparison between the considered cases requires identical internal conditions for each model; therefore, for the masonry building, the size of the air-to-air heat pump has been increased by 50% in Concepción and by 30% in Santiago when compared to wooden buildings. Finally, in Osorno, the city characterized by the coldest climate, the heat pump size was increased by 20% for the timber buildings and by 70% for the masonry building with respect to its commercial size.

The annual energy performance indexes calculated for the three buildings in the three climatic zones is reported in Table 4. The timber buildings (both CLT and timber frame) maintain extremely low EP values for all cities, with 22 kWh/m^2 per year for Concepción, 27 kWh/m^2 per year for Santiago and 28 kWh/m^2 per year for Osorno. Masonry buildings, on the other hand, have higher EP values; for each city the annual energy requirement for heating, cooling and ventilation is about the 25% higher than the one of wooden buildings.

Table 4: Annual energy performance indexes calculated for all cases.

	EP (kWh/m^{2}year)		
City	CLT	Frame	Masonry
Concepción	22	22	29
Santiago	27	27	34
Osorno	28	28	35

The values of SCOP derived from the simulations are around 3.88 and 3.90 for Concepción, while they increase for Santiago, reaching 3.97-3.99. This is due to the fact that the city of Santiago is characterized by cooler temperatures for a longer time during the year, which allows the device to operate with a better efficiency. The same can be said for Osorno, in which the calculated SCOP is equal to 3.99 and 4.00: in fact even for this last city the temperatures are lower than those of Concepción. The SEER index is analyzed in order to evaluate the performance of the machine during the cooling season: it maintains a constant value of 3 up to the external air temperature of 33°C, temperature above which it starts to slightly drop.

CONCLUSIONS

The research work investigated the energy performance of timber and masonry buildings through the simulation in different Chilean cities (Santiago, Concepción and Osorno). The reference building considered in this work is a real CLT construction located in Italy and characterized by two independent dwellings with a floor area of 150 m^2 each. The energy performance of the building and its HVAC system were simulated with the dynamic software TRNSYS. In the reference building, each apartment was equipped with a dehumidifier and controlled mechanical ventilation system, both necessary to guarantee internal air freshness and to maintain humidity within limits that avoid the degradation of wood elements. From the simulations, an ideal energy requirement of 19 kWh/m^2 and 12 kWh/m^2 per year was obtained for the winter and the summer season, respectively, extremely low values due to the considerable insulation of the building.

The envelope of the building was then modified to simulate a timber frame and a masonry building encompassing the same geometrical characteristics. In this way, the differences among the construction techniques were analyzed, taking into account the annual energy performance of the HVAC system. The annual simulations of the nine considered cases were carried out, obtaining first the ideal annual energy requirement of the building envelope. Space cooling energy need is present only in Santiago, albeit in minimal quantities (3 kWh/m^2 per year). On the contrary, it was noted that the two wooden structures show the same energy demand for space heating (24 and 25 kWh/m^2 per year for the cities of Santiago and Concepción, 36 kWh/m^2 per year for the city of Osorno) while the masonry structure is linked to an increase of 26% for the heating energy needs.

Then, the work focused on the optimization of the HVAC system to be combined with the nine analyzed structures. The importance of maintaining humidity levels within limited ranges has led to the choice of a controlled mechanical ventilation system, equipped with an active dynamic heat recovery unit that uses a reversible air-to-air heat pump so satisfy heating and cooling energy needs. This system allows to cool, heat and ventilate through a single device. A further advantage of the chosen unit is that it can exploit free-cooling during the summer, due to the large daily thermal excursion typical of Chilean climate. The results point out that the masonry construction type is in any case the structure that requires the greatest energy consumption (about 25% more than both the wooden typologies), which is partly justified by the fact that, given the same thickness of the external wall, the masonry structure is less insulated.

REFERENCES

Byrne, P. et al. (2009), Design and simulation of a heat pump for simultaneous heating and cooling using HFC or CO2 as a working fluid.

DM Sviluppo economico 26 giugno 2015, “Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici”.

EPBD recast, (2010), Directive 2010/31/EU, Energy Performance of Building Directive Recast.

Klein SA, et al. (2010), TRNSYS 17: A Transient System Simulation.

New EPBD, (2018) Directive 2018/844/EU, Energy Performance of Building Directive 2nd Recast.

ISO, (2005). ISO 7730: Ergonomics of the thermal environment - analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

NTM 011/2 (2014). Requisitos y mecanismos de acreditación para acondicionamiemto ambiental de las edificaciones. Parte 2: Comportamiento higrotérmico. Anteproyecto de norma

NTM 011/3 (2014). Requisitos y mecanismos de acreditación para acondicionamiemto ambiental de las edificaciones. Parte 2: Calidad del aire interiror. Anteproyecto de norma.

NCh853 (2007). Acondicionamiento térmico – Envolvente térmica de edificios – Cálculo de resistencias y transmitancias térmicas. Norma Chilena.

Payam, N. et al. (2014), A global review of energy consumption, CO2 emissions and policy in the residential sector.

Tricallotis, M. et al. (2018), The impacts of forest certification for Chilean forestry businesses.

UNI (2014), UNI/TS 11300-1. Prestazioni energetiche degli edifici - Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale.