624: Effective architectural design strategies for thermal comfort and energy efficiency in two nursery schools in Chile

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Abstract

Two nursery schools for different regions of Chile were designed considering criterion of reaching comfort with energy efficiency. Main strategies considered were: thermal insulation, low air permeability, double glazing windows, orientation and space distribution of different rooms of buildings. To avoid overheating, roof ventilation and solar protection were applied. Towns considered are: Villarrica (39°20S;72°15'W) and María Pinto(33°30'S;71°10'W).
Opaque vertical envelope has been designed of timber frame panels with thermal insulation. An exterior ventilated cavity under the external skin was implemented. Using mock-ups, an experimental procedure for estimating the opened exterior cavity effect in the inside temperature during summer was applied. Measurements showed that inside maximum temperature decreased in approximately 4°C in mock-ups with exterior ventilated cavities, respecting to those without it.
During the design process, effectiveness of solar protection systems and natural lighting were studied with ECOTECT. TAS software was used for estimating heating energy demand and inside temperature variation. TAS simulations predicted that overheating may be easily avoided. Heating demand was 12.9 kWh/m2 year in school of Villarrica and 14,9 kWh/m2 year in school of M.Pinto. According to nurses' opinions of school of Villarrica, inside thermal conditions reached in the new building are significantly better than those of their precedent buildings.

Keywords: comfort, energy efficiency, nursery school, timber frame, overheating

1. Introduction

Chile shows a significant economical growth during the lasts two decades with a parallel increasing in primary energy demand. From 1986 and 2000, demand of electricity grew in 8.2% and even during early 2000's, increasing of electricity demand exceeded the GBP growth. Energy efficiency in different sectors of the national economy has not been part of results of implemented policies for the country's economic growth. Only in recent years the government has created the energy efficiency program, whose results globally are still to be seen in the coming years [1].
Moreover, the country shows a high dependence on energy resources needed for its economic development. In fact the country imports 97% of oil, 84% of coal and 78% of its natural gas requirements [1]. Renewable energy production is very small.
Within the building sector, the country only shows a mandatory Regulation for residential buildings with very weak standards. Even if it has been important for the country to establish this Regulation, required standards are far away from achieving residential housing energy efficiency. In fact, in a large part of the country (including Santiago -33°26'S; 70°41'W- with 6 million inhabitants and 40% of the population of the nation; Degree-days base 18°C = 1900°C) the wall U-value required standard is 1.9 W/K m2. The standard for Concepción and Talcahuano cities (36°35'S;72°02'W. Degree-days base 18°C = 2400°C) is 1.7 W/K m2. This urban area includes other urban surroundings representing 8.1 % of the national total inhabitants. It is important to say that a third urban area of central Chile, which includes Valparaiso (33°01'S;71°39'W), Viña del Mar and areas in the neighbourhood (Degree-days Base 18°C = 1500°C), has 1.540.000 inhabitants, and has a very high U value: 3,0 W/m2 K [2].
For other types of buildings there is no mandatory regulation and with some exception of regional authorities and private clients, no criteria for energy efficiency are applied for architectural design of buildings. At the moment, the government scheduled the design of regulations for the tertiary sector of buildings.
In Chile, one of the main opponents to establish regulations for energy efficiency of buildings is the private sector of the construction. This sector refuses to accept such regulations because of cost increasing in construction. This makes that any initiative that aims to improve energy efficiency in buildings -especially those who may be part of some state program such as educational buildings- must be ideally made considering current costs of construction, which is associated with a low standard buildings in terms of energy demand and users' comfort. This also means that even though the country has an interesting potential in climate conditions, no

initiatives on building design to achieve zero energy is known.

On the other hand, in Chile, an important program is being developed in order to build a set of nursery schools in central and southern regions of the country. Around 400 of schools are planned to be built with the next two years. The objective of this State Program is to improve quality of services that this type of schools offer to communities, which mainly belong to low income sector. One objective of this plan is to improve quality of the inside ambient of the building, in order to generate better conditions for children and nurse.

This paper presents the energy performance and comfort conditions achieved in two nursery schools designed for two different regions of the country. The first one was already built in Villarrica, south of Santiago and the second will be located in Maria Pinto, a small town near Santiago. The construction of the latter is expected to be completed in the coming months. These projects have been implemented within the framework of activities of the Centre for Innovation and Development of Wood (CIDM), Catholic University of Chile.

2. Climate and design of nursery schools

2.1 International experiences

Schools thermal performance has been extensively studied in different countries, showing that energy efficiency is possible to be achieved with different design strategies according to climate conditions. Comfort, energy consumption, air quality and overheating risks have been studied in different types of schools and under different scenarios [3,4].

A research developed in Israel showed the impact on cooling and heating energy saving in warm and moderate climates of this country. The study concluded that building orientation, thermal resistance of walls, roofs and windows must be restricted for energy efficiency. Ventilation rates, especially for inside conditions in heating periods must be controlled. For cooling purposes, certain "preferred ventilation schemes" are proposed [5].

Another study made in south of Portugal shows that winter comfort is no achieved in rooms of schools with north oriented windows and in spaces with windows with some shading device (that probably avoid solar gains in winter). In these cases, electric air heating systems were necessary for reaching comfort. A solar air collector for preheating air during winter was an effective strategy applied in a studied building [6].

On the other hand, a study about day lighting in Curitiba, Brazil showed that school building design shading systems must be carefully designed in order to decrease overheating and avoid excess daylight [5].

2.2 Climate

Schools studied in present work are located in Mediterranean climates, with low temperatures during winter and high temperatures during summer : Maria Pinto (33°30'S;71°10'W) and Villarrica (39°20S;72°15'W). Mean maximum temperature in María Pinto is 29.8 (January). Mean minimum temperature is 2,5°C(July). Villarrica shows a mean maximum temperature of 24 °C (February) and mean minimum of 3,9°C (August). Solar radiation in Maria Pinto is around 220 kWh/m^{2}month for December and January, moths with higher sun exposition and around 24 kWh/m^{2}month for months of winter as June and July [7].

2.3 Design strategies

Regarding to design considerations, climate of both towns suggest the use of solar protection for summer period. High temperatures and incident solar radiation may generate a high overheating risk, especially if in both buildings, timber frame panels were considered.

On the other hand, and also to avoid overheating, a ventilated roof and an air ventilated external cavity in the envelope wall may be effective. In Scandinavian countries and Canada, the external ventilated cavity in timer frame walls is mainly associated to the need moisture evacuation from inside the panel. In our case, although it was also assumed for the same purpose, effectiveness to prevent overheating in summer was also showed.

In order to maximize solar gains, northern orientation of windows was considered. To the south, rooms with less intensive use were privileged. Thermal insulation in ceiling and walls were significantly higher than those defined by housing regulation of the country.

The wall of buildings was developed within a research project to improve the current technology of wood construction in Chile, a country with high forest resources but with low use of wood in construction. The timber frame wall was designed to avoid different pathologies, traditionally related to the wood construction in Chile (humidity, acoustic, thermal insulation, termites and others). Following figure shows a scheme of the wall.

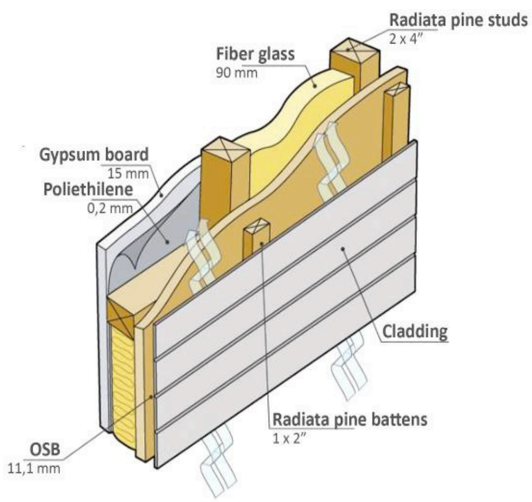

Fig 1. Envelope wall of buildings

2.4 Effect on overheating risk of external ventilated cavity of walls.

Additionally, the external ventilated cavity also contributes to reduce phenomena of overheating in wooden houses. In order to quantify this effect an experimental procedure was developed as follows: four identical modules of 2.4 x 2.4 x 2.4 m were built, with ventilated attic, 100 mm of ceiling thermal insulation and external panels according to specifications (see Fig. 1). The four modules had identical orientation and were placed in the courtyard of DICTUC laboratory (in Santiago), responsible of making the installation, calibration and collected the obtained data. One of the four modules remained as pattern during tests (without ventilated air cavity), with the aim to be compared with the rest (with ventilated air cavity), which suffer a series of changes depending on the kind of test. In all modules, a series of thermocouples were installed in order to register internal temperatures (in the centre of each module), surface temperatures and temperature inside the cavity. The first question to be solved therefore was about the effect that the ventilated air cavity has in the internal temperatures of the modules. Figure 2 shows a graph with results obtained for the second test, which tried to assess the effect of different kind of envelopes in the internal temperatures. The curves have an almost identical behavior to the three evaluated cases: radiate pine cladding, OSB for exterior sheathing and concrete stucco (all represented with continuous dark blue line in graph of figure2). However, when they are compared with the pattern (without ventilated air cavity), it was clearly demonstrated that the ventilated air cavity reduce internal temperatures of the modules by means of a buffer effect between 3°C and 5°C. The graph of figure 2 shows the temperature difference between the pattern module (green non continuous line) and those with external ventilated cavity and different kind of skins. The highest oscillation is observed in external temperature.

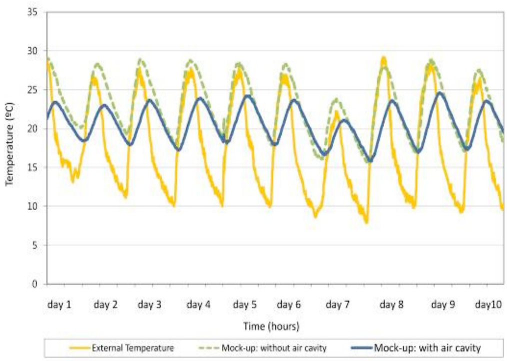

Fig 2. External ventilated cavity in walls: effect on lowering internal temperature

3. Description of buildings

3.1 Nursery school of María Pinto

Figure 3 shows plan of the nursery school of María Pinto with respective surroundings. Building system flexibility permits its adaptation to different contexts and programs. This nursery school will be part of a small town center aside a church and a community hall. Simple and white volumes have low visual impact and integrate with different surroundings. Interior spaces have a functional distribution, good natural lighting and transparency for an adequate control of activities and relation with exterior spaces. Some solar protection devices were designed to avoid overheating and excess of natural lighting in some periods of the year (summer, end of the spring and early autumn).

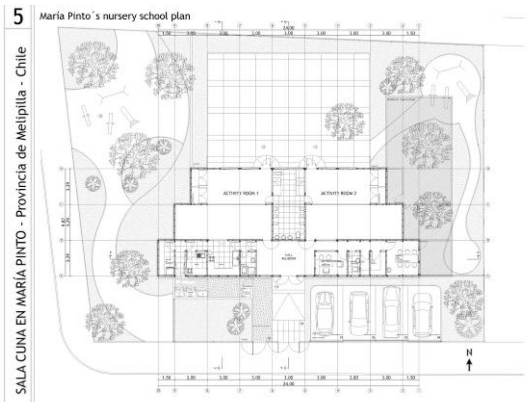

Fig 3. Plan of nursery school of María Pinto. Metropolitan Region. Chile.

As mentioned, the building corresponds to timber frame wall with an external ventilated cavity which collaborates to avoid overheating and to evacuate humidity from the inside of the panel. In order to avoid overheating, a ventilated roof was also considered. See Fig. 4 and 5. The system complies with the Chilean government building costs for nurseries and kindergartens in low income sectors. Building area is 202 m2. Construction considers a high amount of pre-fabrication, which means economy in the building process and ensures better building quality. The simple building process may provide work for small industries and local artisans.

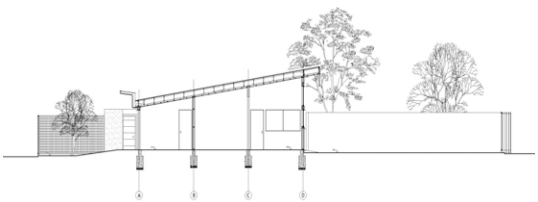

Fig 4. Nursery school of María Pinto. Detail

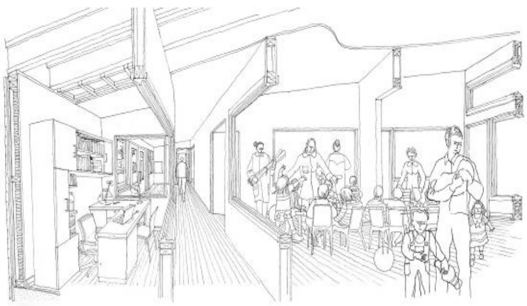

Fig 5. Nursery school of María Pinto. Detail

3.2 Nursery school of Villarrica

This project was constructed during year 2006 an started to be used early in 2007. Building area is 146 m2 and program is similar –bur smaller-than the one of María Pinto. Figure 6 shows a picture of the building.

Fig 6. Nursery school of Villarrica. Chile.

4. Solar protection and daylighting

4.1 Nursery school of María Pinto and Villarrica

To avoid overheating and excessive glare and brightness, especially in summer cooling periods of the year, the buildings count with solar protection, which has proved to be effective to prevent the mentioned problems. In order to study how effective this solar protection was, simulations with ECOTECT were made.

Following figure (Fig 7) shows the effect of solar protection in northern façade. For summer solstice, direct solar radiation on windows is avoided and for winter solstice solar penetration is possible. In some cases, when necessary, for avoiding glare, interior white curtains are used.

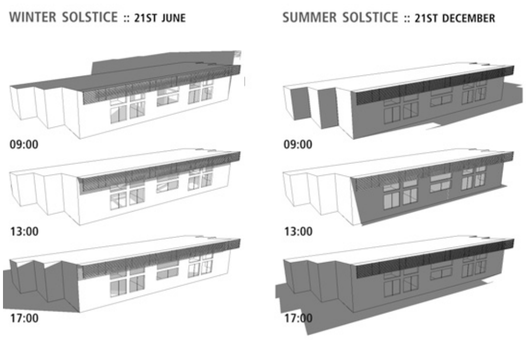

Fig 7. Nursery school of María Pinto. Solar protection in different periods of the year.

A daylight factor study was also made with ECOTECT, considering an overcast sky of 8451 lux and reflection coefficients of 0.70 for ceiling and interior walls and 0.40 for floor.

The study was made for one of the north oriented main rooms. The average value of the daylight factor is 3,57% with some spaces on the back with values under the recommended 2%. In this case, this value is reached by approximately 80% of the plant, higher than the recommended 75% made by the "High Performance Schools, Best Practices Manual. Edition 2006. CHPs: The Collaborative for High Performance Schools. USA ".

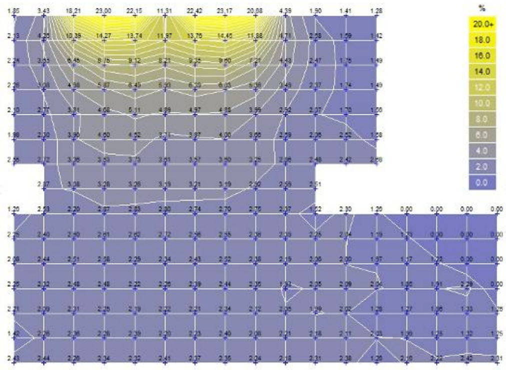

Fig.8. Nursery school of María Pinto. Daylight factor in main activity room 2.

The analysis "daylight autonomy" also shows a satisfactory situation. This indicator is equivalent to autonomy regarding artificial lighting for a certain base value (in this case 500 lux). A study made 3 days of the year (June 21st, September 21st and December 21st) a mean of 80% of the time during these days (between 08:00 and 20:00 hrs) would not be necessary to use the artificial lighting to reach at least 500 lux. Se Fig 9.

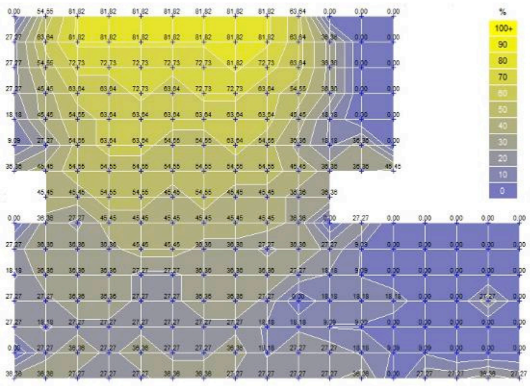

Fig.9. Nursery school of María Pinto. Dayligh autonomy for 500 lux. Main activity room 2. June 21st.

A similar situation is observed in the school of Villarrica, where similar studies were made during the design process. The following pictures (Fig. 10and Fig 11) show the main room of this school without using artificial lighting.

Fig 10. Nursery school of Villarica. Natural lighting in main room.

Fig 11. Children of Nursery school of Villarica. Natural lighting in main room.

5. Thermal performance of buildings.

With the purpose of advising the design process of building, certain studies were made in order to evaluate their thermal behaviour, using TAS software. Heating energy demand for energy and overheating risk were estimated.

Simulations for heating demand were made considering the following operating temperatures:

Week days:
From 7:00 till 20:00 PM; 20°C.
From 20:00 PM till 7:00, no heating.
Summer days with no cooling.
Weekend days: No heating and cooling
Internal gains: according to number of persons and kitchen use.
Ventilation rate: 1ach 24 hours of the day. Nocturnal ventilation with 6.0 ach (from 22:00PM till 7:00 AM was also studied.

Specifications of walls: timber frame with 90 mm of fibber glass. Ceiling with 90 mm of fibber glass. Windows with double glazing (U value of 2,8 W/m^{2}K). Partitions walls are timber frame with gypsum board in both sides. Internal floor: concrete of 14 cm with wood flooring. An internal partition wall of concrete blocs (to increase internal mass) was considered in combination with nocturnal ventilation.

The nursery school of Villarrica reached a heating demand of 12,9 kWh/m^2 year and the heating demand for the school of María Pinto was 14,9 12,9 kWh/m^2 year, which are a lot lower than those of this type of schools according to current type of specifications and design that are being used in the country.

Respecting to overheating risk, both buildings show an effective performance. The following figure shows variation of interior temperature of different rooms in the school of Villarrica. We may observe that inside temperatures in different rooms of the building, temperature is always lower than 26.5°C. We may remark that the main room is north oriented, which makes overheating risk higher, but solar protection and external ventilated cavity in envelope walls –as we have mentioned– has showed to be effective in summer days.

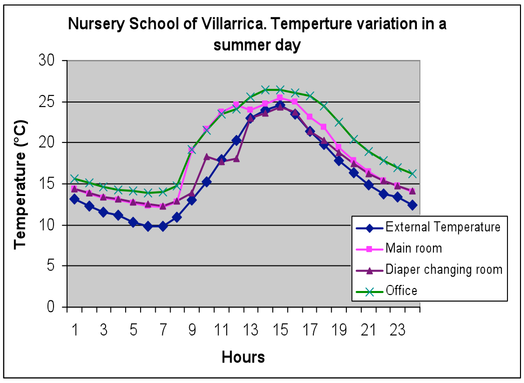

Fig 12. Nursery school of Villarrica. Chile Temperature variation in different rooms in a summer day.

Overheating risk is higher in school of María Pinto than in Villarrica, due to higher temperature and solar radiation. Inside temperatures reach values of 28°C in main rooms and 26,5°C in office room (see figure 7) According to simulations, without solar protection and/or the external ventilated cavity in envelope, temperatures may be even higher than exterior temperature.

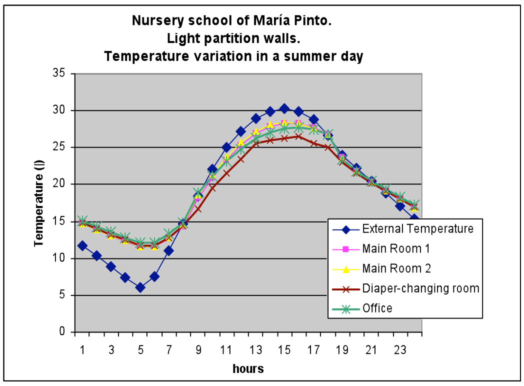

Fig 13. Nursery school of María Pinto. Chile Temperature variation in different rooms in a summer day.

Simulations considering nocturnal ventilation of 6.0 ach and massive internal partitions walls (concrete blocks) showed to be effective to avoid overheating. Inside temperature are lower than the last case, reaching a maximum of 25,5 °C in main rooms and 24,4 °C in office room. See Figure 14.

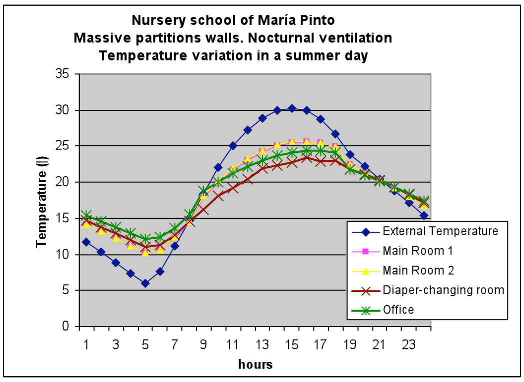

Fig 14. Nursery school of María Pinto. Chile Temperature variation in different rooms in a summer day.

6. Conclusion

Two different projects of nursery schools have been showed. One of them already constructed (Villarrica) and the other one will be finished during the next months (María Pinto).

Both projects have been developed as part of a government programme for massive construction of nursery schools in the country. The projects that we have presented in this paper have had the aim to show that it is possible to design and construct such type of buildings with criterion of reaching comfort with energy efficiency, considering the cost of restrictions imposed by the Chilean construction. In addition, this type of project makes use of wood, an abundant renewable resource of the country. The low heating energy demand, the high standard of daylighting achieved, the low cost of construction and the use of local workforce are advantages that other projects normally built in the country can not show. Moreover, when an employee of the nursery school of Villarrica said that she had improved their working conditions and welfare of children has grown significantly over what was happening in their old building, then we are in front of a solution that remain possible and that is absolutely necessary.

Overheating risk is common in light constructions as timber frame. In this case of Villarrica, with a Mediterranean climate with high temperatures in summer, no internal mass has been used. Solar protection in windows, ventilation in roof, low lighting internal gains, and the use of an external wall with a outer ventilated cavity (see figure 1) to reduce solar gains through opaque envelope has showed to be effective in reducing the mentioned risk. Measurements in mock-ups have showed this positive impact of the external ventilated cavity in envelope walls.

In case of María Pinto nursery school, as simulation showed, overheating may be presented, not as extreme as timber frame buildings normally show, due to solar protection, ventilation in roofs and use of the mentioned ventilated cavity in external walls. When considering nocturnal ventilation in combination with internal thermal mass, performance of the building increases. This strategy is recommended to be used in combination with others considered in the case of Villarrica (roof ventilation, solar protection and external ventilated cavity in opaque envelope).

For winter conditions, due to use of thermal insulation in envelope, north oriented windows, ventilation control and double glazing, heating demand is a significantly lower than normal nursery school of the country.

7. References

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