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Post-Occupancy Evaluation of State Schools in 5 Climatic Zones of Chile

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ABSTRACT
This paper presents the results of a study, commissioned by the Chilean Ministry of Education and UNESCO, of hygro-thermal comfort, visual comfort, acoustics and indoor air quality, as experienced in selected classrooms of 8 state schools located in distinct climatic zones in Chile.

Using a post-occupancy evaluation methodology developed by the authors, 14 classrooms were evaluated with visual analysis, questionnaires and insitu measurements over a 5 day period. Although limited in its duration, the study clearly highlighted deficits in each of the areas of study; these included unacceptable sound pollution arising from transport; overheating due to excessive solar gain; insufficient heating and poorly insulated building fabric; poor indoor air quality; and poor day and electric lighting.

Keywords*: Schools, Comfort, Post-Occupancy Evaluation, Indoor air quality, monitoring*

1. INTRODUCTION

1.1. Background

As a consequence of the introduction in 1997 of full-time mandatory education for children aged between 6 and 13 years [4], the Chilean Ministry of Education (MINEDUC) signed an agreement of collaboration with the United Nations Educational, Scientific and Cultural Organization (UNESCO) to develop the project "Reforma Educativa Chilean: Optimazación de la Inversión en Infrastructura Educativa" (Chilean Educational Reform: Optimization of Investment in Educational Infrastructure). After 12 years in operation and with approximately 1600 [5,6] new educational establishments created, the Chilean Ministry of Education and UNESCO have commission this preliminary study of hygro-thermal, visual and acoustic comfort, and indoor air quality. Whilst previous studies have concentrated on quantity and general design of educational spaces, this is the first to consider their affects on their occupants.
Unfortunately due to the limited timescale allowed by funding constraints this study had to be completed either side of the school summer holidays. For this reason the study focuses solely on those issues arising during the summer months. Based on the findings of this study a more extended study, with more refined methodology and parameters defined by the results presented in this paper, is required. This obviously should include winter months to provide the complete picture.

1.2. Objectives

The aim of this study, though limited in scope, is to begin to ascertain a general overview of comfort provided in the learning environment throughout Chile and how this influences the learning process. Whilst it is unlikely that specific solutions will arise from this study, it is hoped that it will highlight the common problems faced by state schools in Chile and begin to draw general conclusions, allow for the planning of more details studies in the future and the design of solutions.

The parameters evaluated as part of this study were air temperature, internal surface temperate of classroom walls, background noise levels, natural and artificial lighting and levels of carbon dioxide.

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1.2.1. Climatic conditions

Continental Chile stretches from latitude 17.5° to 56° south, and rises from sea level to over 4000m. Within this sliver of geography there exist many climatic regions and distinct microclimates. In order to assist with architectural design 9 climatic zones have been defined under the Chilean standard "NCh 1079 of 77" [1] These are Northern Coast, a coastal desert region; Northern Desert, an arid region including the Atacama Desert; Northern Transverse Valleys, which are characterized by a semi-desert climate; Central Coast, a warm temperate maritime region; Central Interior, with a Mediterranean climate; Southern Coast, with cold temperate maritime characteristics; Southern Interior, a region with a cold temperate climate dominated by temperate rainforest; Extreme South, a large region ranging from cold temperate maritime to sub polar oceanic, requiring further subdivision but scarcely populated; and Andean running the length of the country for altitudes over 1000m above sea level.

For this study classrooms in 8 schools were selected in 5 of these climatic zones, these being Northern Coast, Northern Transverse Valleys, Central Interior, Southern Coast and Extreme South.

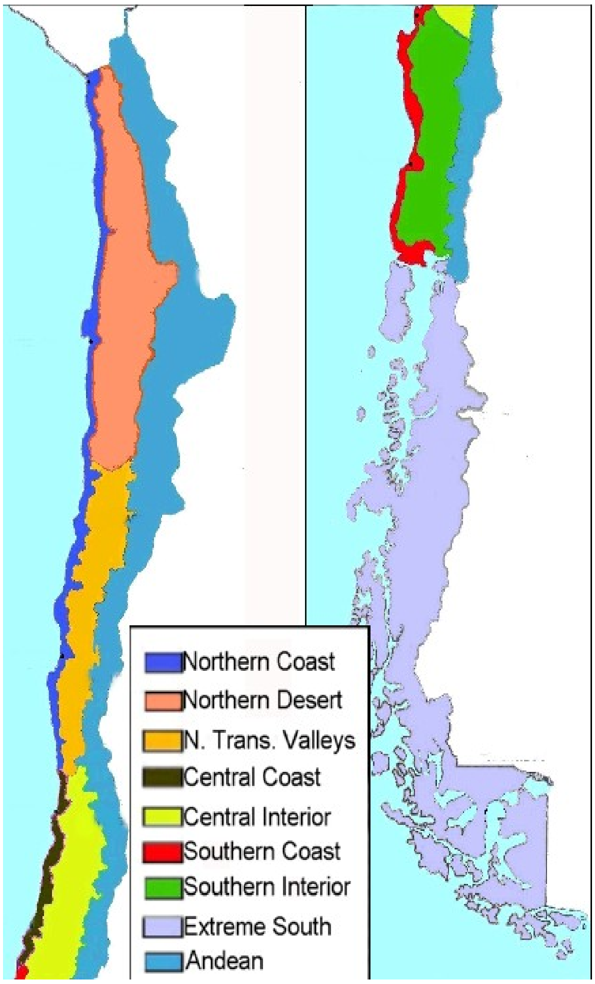

Figure 1. Climatic Zones of Chile, as according to ChileanStandard NCh 1079 of 77

Table1. School location and corresponding climatic zone.

School	Location	Climatic Zone
A	Copiapó	Northern Transverse Valleys.
B		*Semi-desert*
C	Caldera	Northern Coast.
		Coastal desert
D	Santiago	Central Interior.
E		*Mediterranean*
F	Puerto Montt	Southern Coast.
		Cold Temperate Maritime
G	Ancud	Extreme South
		Sub polar oceanic
H	Chonchi	Extreme South
		Sub polar oceanic

1.3. Methodology

The methodology used in this study, common to many Post Occupancy Evaluations, uses a mixture of visual observations, interviews with building managers, anonymous interviews with teachers, and digital measurements, to establish the environmental comfort of the spaces analyzed, whilst in use.

1.3.1. Post-occupancy evaluation

In general the majority of architects, engineers, construction team and even public clients, once a building is completed, rarely return to see it in use and learn from its occupants. This has lead on a global scale to the construction industry being slow to learn from its mistakes or even realize when they have had a simple success [7].

This deficiency within the design process is one that that is slowly being rectified across the world. Early studies of the performance of a students residence by Sim Van der Ryn at the University of California Berkley may have been unique at the time [8], but the same university has gone on to develop its "Vital Signs" program [9] which provides a tool-kit for architectural students to include as part of their education. On the other side of the Atlantic the series of 'Probe Studies' undertaken by Bordass and Leaman in the United Kingdom, starting with the office building Tanfield House in 1995 [10], began to raise the profile of this methodology.

2. CASE STUDIES

2.1. School A, Copiapó- semi-desert

2.1.1 Visual observations

The school is situated with the main road to the north and a side road to the east. The classroom is on the ground floor, facing east. The construction is reinforced concrete, of 250mm overall thickness with a pale green painted plaster internal finish and external un-insulated render. The room is 2.9m high with 17.8% of the wall surface glazed, principally towards the east. No external solar protection is provided with only internal curtains. The artificial lighting consists of 16 fluorescent tubes, which are all switched on.

2.1.2. Photographic records

Figure 2. School A, External view

Figure 3. School A, Internal view of study classroom

2.1.3. Results of measurements

Table2. Table of measurements, school A.
11:00, 30/03/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	23.4	23.6
Rel. Humidity	%	54	72
CO2 levels	P.P.M.	600	1350
Average Surface Temp.	°C	-	22.9
Background Noise level	dBA	75	75
External light level	lux	10,800	-

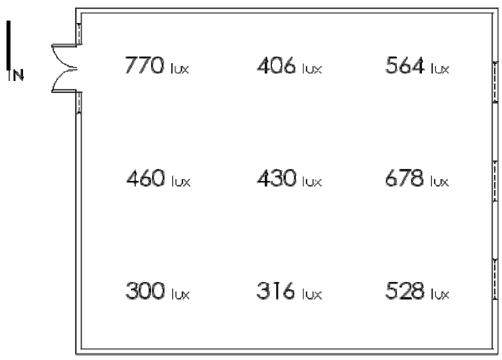

Figure 4. School A, illumination at desk level

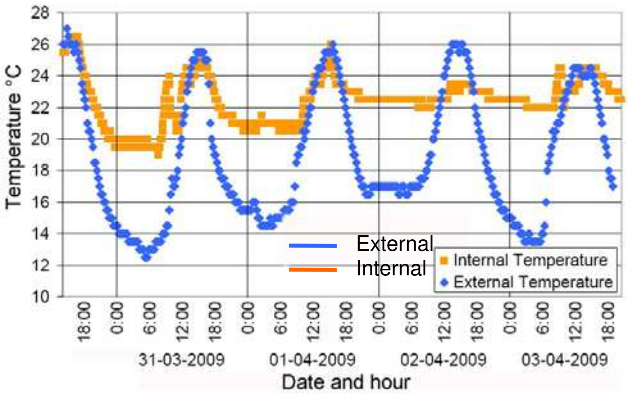

Figure 5. School A, Internal and external temperatures over a 4 day period

2.1.4 Specific conclusions

The principal problem is the noise pollution caused principally by lorries passing on the adjacent road. This was confirmed by the building manager and teachers interviewed who reported rated this nuisance as 5 (on a scale of 1-6) and its interference with their work as 6, with the necessity to interrupt classes each time a lorry passes. The noise also results in poor ventilation due to reluctance to open windows.

At an urban scale the offending lorries could be redirected via an alternative route, or prohibited during school hours. Otherwise the use of hermetically sealed double glazing with mechanical ventilation should be considered.

2.2. School B, Copiapó- semi-desert

2.2.1. Visual observations

The school is situated within its own grounds. To the west, the direction of the predominant wind (SW), is located a bare earth football pitch. The classroom is situated on the ground floor, facing north. The construction is reinforced concrete, of 270mm overall thickness with a pale yellow painted plaster internal finish and external un-insulated render. The room is 2.7m high with 17% of the wall surface glazed, principally towards the North. No external solar protection is provided with only internal curtains. The artificial lighting consists of 14 fluorescent tubes, which are all switched off.

2.2.2. Photographic records

Figure 6. School B, External view

Figure 7. School B, Internal view of study classroom

2.2.3. Results of measurements

Table3. Table of measurements, school B.
11:00, 31/03/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	21	22.8
Rel. Humidity	%	70	71
CO2 levels	P.P.M.	630	1250
Average Surface Temp.	°C	-	23.7
Background Noise level	dBA	65 -78	60-65
External light level	lux	10,800	-

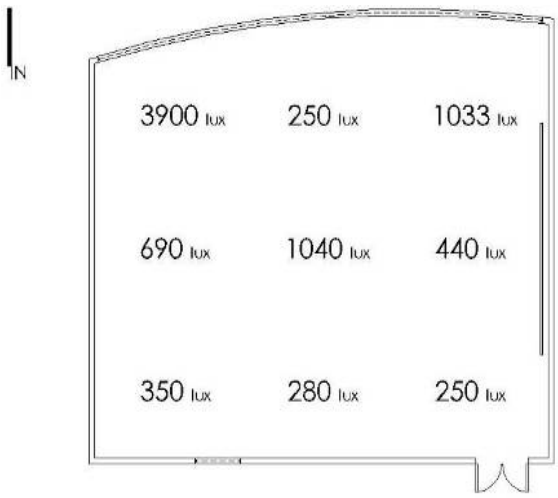

Figure 8. School B, illumination at desk level

2.2.4. Specific conclusions

A third of teachers interviewed experienced discomfort from glare arising from the lack of external solar protection. In turn this leads to internal curtains often being closed, thus reducing natural daylighting and augmenting the reliance on artificial illumination.

Horizontal shading, perhaps in the form of a light shelf could reduce glare and provide more homogeneous daylighting.

Teachers interviewed reported that the location of the bare earth football pitch causes problems with dust and prohibits the opening of windows. The simplest solution would be to surface the pitch or create a windbreak with trees and shrubs.

2.3. School C, Caldera- coastal desert

2.3.1. Visual observations

The school is occupies an entire urban block in the town centre. The classroom is situated on the ground floor, facing west. The construction is a steel frame with un-insulated 90mm brick, or 40mm solid panel infill. The internal finish is apricot painted plaster. The room is 2.7m high with 17% of the wall surface glazed, principally towards the west. Planting provides limited external solar protection, supplemented by internal curtains. The artificial lighting consists of 4 low energy pendant bulbs, which are all switched on.

2.3.2. Photographic records

Figure 9. School C, External view

Figure 10. School C, Internal view of study classroom

2.3.3. Results of measurements

Table 4. Table of measurements, school C.
11:00, 01/04/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	21.8	23
Rel. Humidity	%	62	80
CO2 levels	P.P.M.	610	1450
Average Surface Temp.	°C	-	25.3
Background Noise level	dBA	62	75
External light level	lux	48,000	-

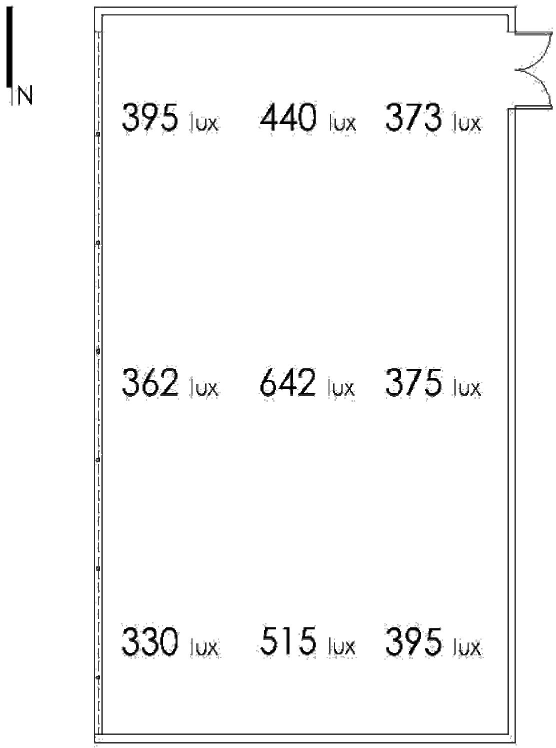

Figure 11. School C, illumination at desk level

2.3.4. Specific conclusions

School C again suffers similar problems regarding noise pollution, leading to poor ventilation, in addition to lack of solar protection.

2.4. School D, Santiago- Mediterranean climate

2.4.1. Visual observations

The school is situated in the city centre, occupying the corner of a city block. Two classrooms were studied both situated on the top floor of a three story block, one facing east, the other west. The construction is reinforced concrete, of 200mm overall thickness with a yellow painted plaster internal finish and external un-insulated render. The rooms are 3.5m high. The east facing room has 20% glazing distributed both east and west walls with no external shading and internal curtains. The west facing room has 12.5% of the wall surface glazed, principally towards the west. External vertical panels provide solar protection, supplemented by internal curtains. In both classrooms the artificial lighting consists of 14 fluorescent tubes, which are all switched on.

2.4.2 Photographic records

Figure 12. School D, External view

Figure 13. School D, Internal view of eastern classroom

Figure 14. School D, Internal view of western classroom

2.4.3. Results of measurements

Table 5. Table of measurements, school D
East classroom 12:00, 04/12/2008, early summer

Parameter	Units	External	Internal
Air Temp.	°C	24	25
Rel. Humidity	%	-	52
CO2 levels	P.P.M.	-	1350
Average Surface Temp.	°C	-	25.5
Background Noise level	dBA	-	69 -76
External light	lux	7000	-

Table 6. Table of measurements, school D
West classroom 12:30, 04/12/2008, early summer

Parameter	Units	External	Internal
Air Temp.	°C	24	25.5
CO2 levels	P.P.M.	-	772
Average Surface Temp.	°C	-	25.5
Background Noise level	dBA	-	62-74
External light level	lux	7000	-

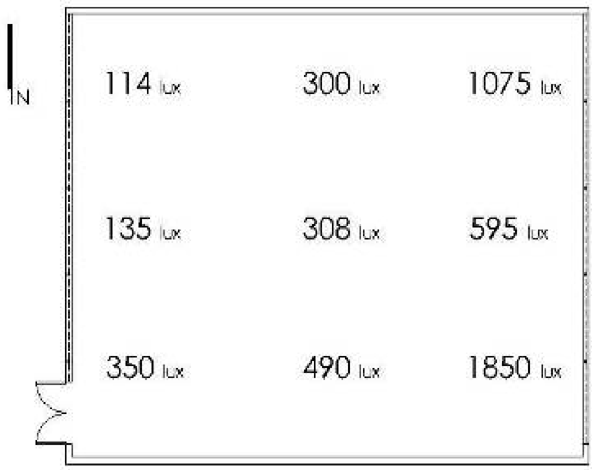

Figure 15. School D, illumination at desk level
Eastern Classroom

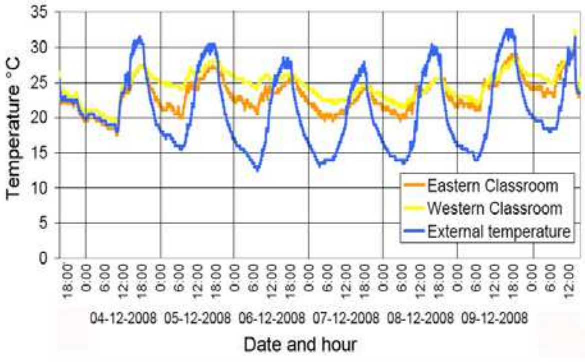

Figure 16. School D, Internal and external temperatures over a 6 day period

2.4.4. Specific conclusions

Once again, due to the schools city centre location, noise pollution is the principal problem faced by school D. Of the teachers interviewed all reported that background noise levels interfere with their work. They confirmed a constant conflict between external noise when windows are open and poor indoor air quality and serious overheating when windows remain closed.

The complexity of the inner-city location would make urban transport control an unlikely solution, therefore hermetic high performance glazing with mechanical ventilation could perhaps be the most appropriate solution. This could be coupled with the use of night purging to take advantage of the low nocturnal temperatures experienced in Santiago, and the high thermal mass inherent in the buildings construction, to help reduce summer peak temperatures.

2.5. School E, Santiago- Mediterranean climate

2.5.1. Visual observations

The school is situated in a quiet residential neighbourhood fronting onto a square. The classroom is situated on the ground floor facing north. The construction is solid brick, of 250mm overall thickness with an apricot painted plaster internal finish and external un-insulated render. The room is 3.2m high and has 17% of wall surface glazed, distributed equally between external wall and that to the internal patio. No external solar protection is provided with only internal curtains. The artificial lighting consists of 6 fluorescent tubes, the lights are all switched on.

2.5.2. Photographic records

Figure 17. School E, External view

Figure 18. School E, Internal view of study classroom

2.5.3. Results of measurements

Table 7. Table of measurements, school E.
10:20, 09/12/2008, early summer

Parameter	Units	External	Internal
Air Temp.	°C	26.8	19.9
Rel. Humidity	%	44	76
CO2 levels	P.P.M.	-	950
Average Surface Temp.	°C	-	26.6
Background Noise level	dBA	-	45 -66
External light level	lux	17,500	-

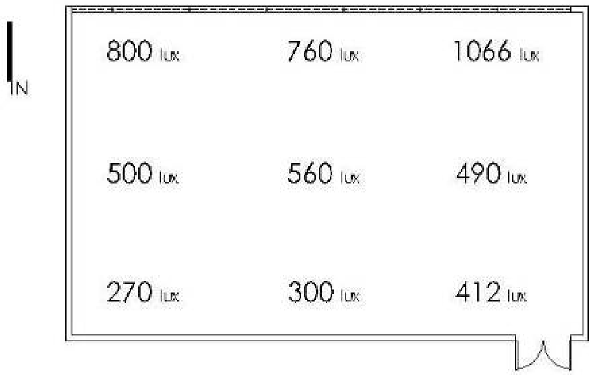

Figure 19. School E, illumination at desk level

2.5.4. Specific conclusions

Due to its location in a quiet residential neighbourhood noise pollution an issue and so natural ventilation via opening windows is possible. The high levels of thermal mass provided by construction help regulate temperatures during the summer months; however it is likely that the lack of insulation leads to discomfort from the cold in winter and problems with condensation. Due to a reluctance of teachers to participate in the proposed interviews it is not possible to confirm this.

2.6. School F, Puerto Montt- Cold Temperate Maritime

2.6.1. Visual observations

The school is situated in a rural location but is adjacent to the cities airport. The classroom is situated on the ground floor, facing north. The construction is timber framed with un-insulated timber panel infill painted pale yellow internally. The windows are fixed shut due to noise pollution from adjacent airport. No external solar protection is provided with only internal curtains. The artificial lighting consists of fluorescent tubes, which are all switched off.

2.6.2. Photographic records

Figure 20. School F, External view

Figure 21. School F, Internal view of study classroom

2.6.3. Results of measurements

Table 8. Table of measurements, school F.
15:20, 18/03/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	17	24
Rel. Humidity	%	82	84
CO2 levels	P.P.M.	630	2600
Average Surface Temp.	°C	-	23
Background Noise level	dBA	76-80	79-80
Average light level	lux	6000	1417

2.6.4. Specific conclusions
At school F the problem of external noise pollution is taken to its extreme due to the schools inappropriate location besides the airport. All teachers interviewed confirmed that it was necessary to interrupt their classes each time a plane lands or takes off. They also confirmed that with the windows fixed shut the classroom is stuffy with insufficient ventilation and high humidity. Whilst there exists possible new-build solutions to this problem the most effective and affordable solution would be to relocate the school, a solution that the local authorities are currently pursuing.

2.7. School G, Ancud- Sub polar oceanic
2.7.1. Visual observations
The school is situated near the seafront close to centre of town, with a central atrium with translucent roof. The classroom is situated on the second floor, facing east. The construction is reinforced concrete with pale yellow painted plaster internally. No external solar protection or internal curtains are provided. The artificial lighting consists of 8 fluorescent tubes, which are all switched off.

2.7.2. Photographic records

Figure 22. School G, External view

Figure 23. School G, Internal atrium

2.7.3. Results of measurements

Table 9. Table of measurements, school G.
10:30, 19/03/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	14	22
Rel. Humidity	%	99	85
CO2 levels	P.P.M.	-	2600
Average Surface Temp.	°C	-	20.1
Background Noise level	dBA	-	66-73
Average light level	lux	11,500	578

2.7.4. Specific conclusions
The central atrium provides a vibrant centre to the school and provides a well-lit protected space for recreation throughout the year. However the lack of acoustically absorbent materials in this space leads to poor acoustics and complaints by teachers.

The introduction of absorbent materials, such as acoustic wall or ceiling panels would help reduce the reverberation time of the space.

In interviews the teachers' most common complaint was that of the cold, 80% wear outdoor coats for winter classes. The problem is aggravated by problems with the under floor heating system. It is unclear if this is a mechanical or economic problem, but it is clear that the lack of insulation in the building envelope clearly does not help. Inadequate ventilation was also once again highlighted, this time due to low outdoor air temperatures and associated draughts. The insulation of the building envelope and mechanical ventilation with heat recovery should be considered.

2.8. School H, Chonchi- sub polar oceanic
2.8.1. Visual observations
The school is recently constructed and is the only school studied with thermal insulation. It is situated in the upper part of the village overlooking the bay, with a central atrium. The classroom is situated first floor, facing east. The construction is timber framed with 100mm of insulation, clad internally and externally in timber. The room has glazing to the east and south. No external solar protection is provided with only internal curtains. The artificial lighting consists of 6 fittings each with 3 fluorescent tubes, which are all switched on.

2.8.2. Photographic records

Figure 24. School H, External view

Figure 25. School H, Internal view of study classroom

2.8.3. Results of measurements

Table 10. Table of measurements, school H.
14:30, 19/03/2009, early autumn

Parameter	Units	External	Internal
Air Temp.	°C	16	25.3
Rel. Humidity	%	94	77
CO2 levels	P.P.M.	-	1545
Average Surface Temp.	°C	-	23.3
Background Noise level	dBA	-	63-67
Average light level	lux	11,000	742

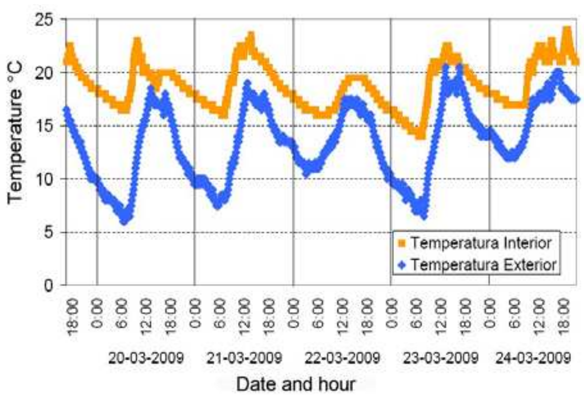

Figure 26. School H, Internal and external temperatures over a 6 day period

2.7.4. Specific conclusions

Being the only school in the study with an insulted building envelope it is not surprising to see that the indoor air temperature stays constantly above the external. Due to its recent completion the building manager and teachers have not yet experienced a winter in the building, however it is possible that the natural ventilation strategy of simple opening windows may prove problematic given the local climatic conditions.

The central atrium suffers similar acoustic problems as those encountered at school G. In addition the space suffers from complete lack of ventilation with no opening windows or mechanical ventilation, a problem also experienced in the kitchen and dinning room of the school.

3. FINAL CONCLUSIONS

The results of this study, both those measured and those compiled from the building manager and teacher interviews, highlight many of the principal problems encountered in schools across Chile, these being noise pollution, poor air quality, thermal discomfort and poor lighting. It is interesting to note that in the interviews teachers concentrated on the first three problems, often not noting poor lighting even when light levels were far below accepted standards.

These problems directly impact on the performance of both pupils and teachers and ultimately on the standard of education. For this reason it is important that post occupancy evaluation becomes an ongoing, integral component of the Ministry of Education's management and design of educational establishments.

3.1. Noise Pollution

The most common problem, experienced to varying degrees in all the schools studied, is that of noise pollution. In two of the schools studied, D and F, the teachers interviewed described the problem as so extreme as to prevent communication between teacher and student. A study by Prichard and Bradley, in 2001[11] showed that above background noise levels 40dBA most teenagers (12+) have problems with speech recognition, with school children aged 6-7 encountering problems above 28.5dBA. In all schools studied it can therefore be concluded that students' performance is being adversely affected by their learning environment.

It is logical, and indeed desirable when considering sustainable urbanism, to locate schools in populated areas with good transport connections. However if educational buildings are not designed with classroom acoustics in mind there is an obvious conflict. Currently there exists no Chilean law or standard regarding noise pollution arising from transport and the teaching environment. The only related law DS 146 [12] refers only to 'fixed sources' of noise pollution and thereby omits any arising from mobile sources such as transport.

3.2. Indoor air quality

In all but one school teachers reported a reluctance to open windows. In many cases, especially schools D and F, this was a direct result of the primary problem of noise pollution, however at school B it was a result of poor external air quality and at schools G and H low external temperatures and resulting draughts. Considering that all schools studied rely on natural ventilation through direct opening windows the result is that of generally poor indoor air quality in all climatic zones studied. Studies have proven that increased levels of CO_2 have a direct impact on children's health and performance in the classroom [13], with a measured decrement in Power of Attention of approximately 5% in a study conducted by the Coley and Greeves in 2004 [14].

Whilst natural ventilation is generally accepted to be a key component to sustainable architecture, the results of this study would suggest that it is not the optimum solution for the teaching environment especially when located in urban areas, areas with airborne pollution or cold climates. In addition a reliance on teachers opening windows is problematic. As noted in the user interviews undertaken, a concern over acoustic or thermal discomfort often takes priority over that for providing sufficient ventilation and good air quality.

3.3. Illumination

All but one of the classrooms studied presented poor natural daylighting, with problems of glare, uneven distribution and high contrast. This problem was particularly notable in those classrooms in the north and central regions where lack of external shading leads to the need to keep internal curtains closed, thereby relying almost exclusively on artificial lighting, which itself was of poor quality and of low efficiency.

3.4. Hygro-thermal comfort

Given that the study was undertaken during the summer months it is difficult to draw precise conclusions as to the problems faced due to the absence of thermal insulation. However teachers' responses suggest that unacceptably low temperatures are experienced with some reporting the need for them to use outdoor clothing during lessons.
Overheating was encountered in those schools located in areas with hot summers when windows were closed to reduce the acoustic problems previously described.

3.5. Resume

It is evident from this study that although there has been an increase in the quantity of educational establishments in Chile, an increase in quality is still required. Whilst it is encouraging to see that thermal insulation is beginning to be considered in newly built schools in the southern cold climates, an investigation into mechanical or forced ventilation appropriate for the Chilean climates and economic situation is clearly a necessity.

When designing new buildings architects should approach these problems in an integrated way in order to optimize all parameters and their interactions. In particular, the careful design of windows is critical if they are to maximise natural daylighting, provide an adequate acoustic barrier to external noise pollution, be an integral part of a ventilation strategy which minimises energy loss whilst maximising indoor air quality, and by doing so create a comfortable friendly learning environment.

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