Post Occupancy Evaluation and User Behaviour as the Basis of the Design of Energy Efficient Dwellings for Temuco-Padre Las Casas, a City Declared Saturated by Airborne Pollution.

Speakers:
Armijo, G[1]; Whitman, C[2]; Roubelat, L[3]

[1] Universidad Central, FAUP, LABBIO, Santiago, Chile
[2] Universidad Central, FAUP, LABBIO, Santiago, Chile
[3] Universidad Central, FAUP, LABBIO, Santiago, Chile

Abstract: *The cities of Chile's Central Valley face a serious problem regarding airborne pollution with many already declared saturated in terms of PM10. This pollution is directly related to the thermally inadequate housing stock and the use of inefficient wood burning appliances. This paper presents the initial stages of research for the project "Environmentally Efficient Dwellings: Design Guide for the Construction and Management of Sustainable Mixed Use Residential Buildings for Southern Central Chile." To gain an understanding of the current situation, post occupancy evaluation and a study of occupants' behaviour was undertaken of dwellings in the city of Temuco, a city declared saturated by airborne pollution PM10 and PM2.5. This evaluation helps to build a picture of the reality of daily life both in winter and summer months, a picture that will enable the resulting guide to closely fit the needs and realities of the population of Chile's Central Valley.*

Key words, Energy efficiency, airborne pollution, Post occupancy evaluation, user behaviour

Introduction

In Chile the architectural design of all types of residential developments, and their related services, occurs with no significant consideration of sustainability or energy efficiency. This lack of consideration not only results in low standards of habitability (IC 2006) but also in the associated, ever increasing operational costs. These problems are compounded in Chile's Central Valley, home to over 50% of the country's population (INE 2012), where the topography traps the airborne pollution and most cities have been officially declared saturated by airborne contamination PM10 by the Ministry of the Environment. These emissions are principally from the burning of firewood for heating and cooking, with poor quality firewood, inefficient stoves and a housing stock lacking sufficient thermal insulation being the principal contributing factors. Studies show that the application of current Thermal Regulations and improve air tightness could reduce emissions of particular matter by 53% (Ulloa et al. 2010). A programme to implement these measures is currently being applied in the city of Temuco. At the same time research by the authors of international case studies show that there exists the necessary technology and knowledge needed to design, build and inhabit sustainable mixed use residential buildings; a housing typology that the authors believe could help solve many of the problems faced by cities in Chile's Central Valley (Whitman et al. 2013).

Objectives

As part of the research project "Environmentally Efficient Dwellings: Design Guide for the Construction and Management of Sustainable Mixed Use Residential Buildings for Southern

Central Chile," funded by the *Dirrección de Investigación y Postgrado* of the Universidad Central de Chile, post occupancy evaluation and a study of occupants' behaviour was undertaken in order to give an insight into the current situation in dwellings in the city of Temuco-Padre Las Casas, a city declared saturated by airborne contamination PM10 in 2005 (Minsegpres 2005) and PM2.5 (MMA 2013) in 2013. This evaluation and study was specifically requested by the regional office of the Ministry of Housing and Urbanism to help build a picture of the reality of daily life both in winter and summer months. With the knowledge obtained from this study it is hoped that the resulting design guide will closely fit the needs and realities of the population of Chile's Central Valley, promoting the design of energy efficient dwellings, the impact of which will contribute, along with other measures, to help to build a sustainable future for those cities declared saturated by airborne pollution.

Methodology

Selection of case studies

The case studies were selected with the help of the regional office of the Ministry of Housing. Three criteria were used for their selection, firstly their representation of the main existing housing typologies in Temuco, secondly the different ways in which a government subsidy for thermal refurbishment had been applied, (this subsidy aims to reduce firewood consumption and resulting airborne contamination) and thirdly the inclusion of projects in neighbourhood improvement programmes, addressing the problem from residential to urban scale. The dwellings selected were as follows: **Barros Arana:** A ground floor apartment in one of two social housing blocks built in 1959 and refurbished in 2012. The thermal refurbishment consisted of 20cm Externally Insulated Façade System (EIFS) achieving a thermal conductivity of U=0.56 W/m²K. The cast iron windows were replaced with aluminium frames improving air-tightness but double glazing was not installed due to cost constraints. **La Haya:** A third floor apartment in a new-build private residential building built in 2011. This building is one of a series of buildings by the developers Schiele y Werth Ltda that specifically include their energy efficiency in their marketing. The building has EIFS which exceed the building regulation requirements, uPVC double glazed windows, controlled ventilation and air-to-air heat pump heating. **Población Temuco:** Three terraced houses in a social housing estate built in 1960, at different stages of refurbishment. One of the three remains un-insulated as built; the second has been refurbished with insulation to external walls and loft but with no change to the single glazed timber framed windows, whilst the third has had only one of its two external walls insulated but all windows have been replaced with uPVC double glazed units. All three are of the same plan-type and enable a clear comparison between the applications of the subsidy.

Measurements

The post occupancy evaluation consisted of the following elements; a visual inspection of the dwelling noting dimensions, materiality, orientation and installations; structured recorded interviews with occupants; discrete in situ measurements of hygrothermal variables (dry-bulb temperature, relative humidity, radiant surface temperatures and thermal imaging) and non-hygrothermal variables (sound pressure, daylighting and concentration of carbon dioxide);

continuous hygrothermal measurements (dry-bulb temperature and relative humidity) with wireless hygrothermic sensors (ibutton Hydrocron) suspended at a height 1.7m above floor level; and logbooks of daily ventilation and heating habits recorded by the occupants during the period of continuous hygrothermal measurements. The logbooks also recorded the number of guests at the house as this affects the internal gains and may possibly affect the occupant behaviour. This information was then analysed with the hope of finding clues and highlight environmental conflicts or assets to be taken into account with new dwellings design.

Results

Winter Higrothermal Measurements

The results of the measurements in the two apartments from the 14th until 24th September 2013 show that in both cases the temperatures and relative humidity levels are within the hygrothermal comfort zone during the measurement period. In the case of the apartment reconditioned with the government subsidy, Barros Arana, on the 14th August 2013, 17°C was measured internally without heating with an external temperature of 13.6°C. Relative humidity levels were however consistently over 60% suggesting a lack of sufficient ventilation. This is confirmed by the CO2 concentrations recorded which were over 1000 PPM (table 1). It would appear that as a result of the thermal reconditioning the air tightness has been improved, however sufficient background ventilation has not been provided. Superficial condensation problems were also detected at the base of the external walls, with some mould growth. Thermographic imaging confirmed that the external insulation stopped short of the ground, exposing the ground slab, thereby creating a thermal bridge at this point.

The results of the measurements of the three dwellings in Población Temuco, 15th August 2013 until 24th September 2014, show that those with thermal reconditioning provide better levels of hygrothermal comfort (Figs. 1-3). They also show that the replacement of the single glazed windows with double glazing in conjunction with thermal insulation of the walls is more effective than only insulating the walls. Thermographic imaging clearly showed the heat losses through the single glazed windows and poor quality un-insulated timber door.

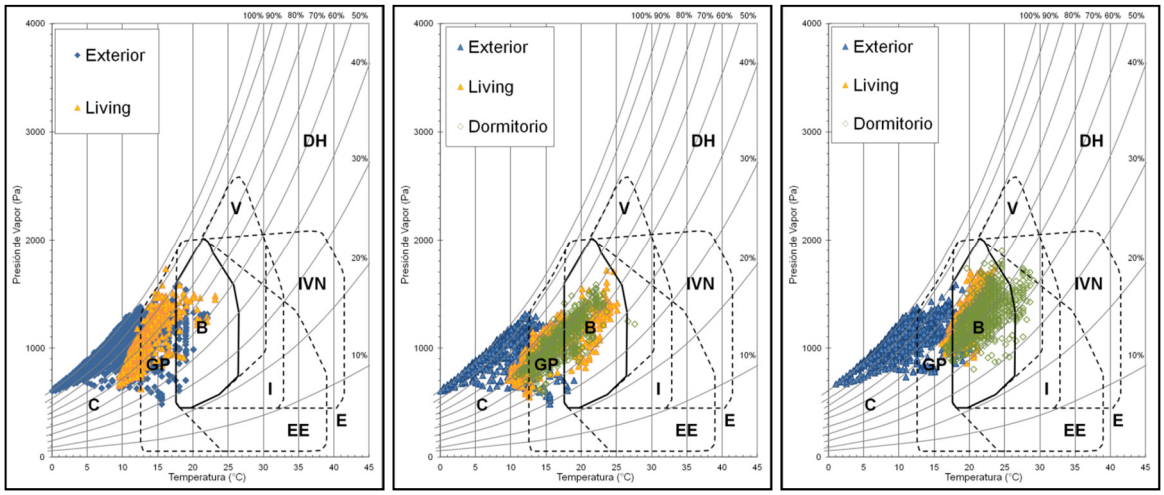
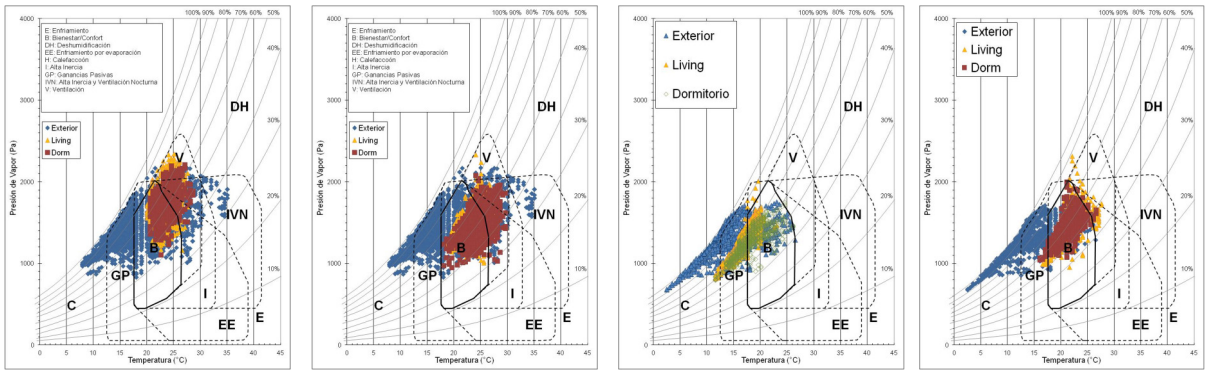


Figure 1: Población Temuco house without insulation. Figure 2: house with insulated walls. Figure 3: house with insulated walls and double glazing (Austral winter)

Summer Hygrothermal Measurements

The results of the summer measurements show that both apartments suffer from overheating during the summer period, 17th January 2014 until 12th March 2014 (figs 4-7), with over half the measurements in Barros Arana falling above the higher limits of the thermal comfort zone and temperatures in La Haya reaching 30°C. In both cases however the internal temperatures remain 5°C below external temperatures that reach 35°C. Overheating is not as evident in the case of the terraced houses and in the case of the un-insulated house temperature are often below the lower limits of thermal comfort. Interviews with the occupants did however report some overheating in the thermally reconditioned house and it should be considered that the terraced houses were measured at the end of summer 20th March until 12th April, later than the apartments, and that during this period external temperatures did not exceed the upper limits of thermal comfort.



Figures 4-7.- Psychrometric Charts of Barros Arana, La Haya, un-insulated house and insulated house. 16/01/2014-01/04/2014 (summer)

Measurements of indoor Carbon Dioxide (CO2) Concentrations

The in situ measurements of CO2 concentrations (table 1.) show that there is insufficient ventilation in the apartment in Barros Arana and also in the house with double glazing. In the house, the concentration is only just above 1000 ppm however the apartment has much higher levels. These results confirm the lack of ventilation suggested by the previously discussed high levels of relative humidity.

Table 1- Measurements of indoor Carbon Dioxide (CO2) Concentrations (PPM) in living rooms of dwellings, August 2012 (winter) & January 2013(summer)

Building	Concentration CO2 (PPM) Winter		Concentration CO2 (PPM) Summer	
	Exterior	Interior	Exterior	Interior
Barros Arana. Apartment.	466	**1098-1700**	440	650
La Haya. Apartment.	470	670	440	530
Población Temuco. Un-insulated house.	478	642-802	484	640
Población Temuco. Insulated house.	480	660-796	-	-
Población Temuco. Insulated house with double glazing	470	**1065**	484	655

Occupant behaviour study

Semi-structured interviews

The results of the semi-structured interviews with the occupants show that the thermal refurbishment provides improved perceived comfort, with the occupants wearing fewer

clothes indoors in winter (table 2). The occupants also reported that the reconditioning has reduced their heating demand. In the case of Barros Arana they have halved their use of firewood; in the insulated terraced house their monthly bill for of paraffin reduced from approximately €93 to approximately €66; whilst in the insulated house with double glazing their use of firewood reduced to one third of that of the previous year. In addition to these achievements the interviews highlighted the enthusiasm of the occupants for the reconditioning program and their extensive knowledge of its scope and aims. In order to achieve the reconditioning of the two blocks at Barros Arana the organization and community participation required (180 owners) is impressive. One occupant of Barros Arana had bought a thermometer to monitor the indoor temperature and many commented on how more schemes like theirs were necessary for the city. This shows that the program has not only improved the energy efficiency and comfort of the homes but also increased the environmental consciousness of the users. This is even more impressive when you consider that thermal refurbishment is in many ways invisible and does not at first glance, to the general public, appear obviously related to improving the air quality of the city.

Table 2- Results of interviews with occupant's (W-winter, S-summer)

	Thermal sensation [1]		Clothing[2]		Opening windows[3]		Drafts		Sufficient daylight		Problems with glare		Problems with noise	Heating season
	W	S	W	S	W	S	W	S	W	S	W	S		
Barros Arana Flat	4		0,9	0,9										April-August
Un-insulated house	3	7	1,2	0,6	Mi	T	sí	no	no	sí	no	no	sí	7 hours daily
Insulated house	4		0,9	0,6										April-Sept.
Insulated house + double glazing	4	5	0,9	0,6	Mo	Af	no	no	sí	sí	no	no	no	April-Dec. 8-10hrs

1. Range 1= cold; 4= comfortable; 7= hot
2. Clo
3. Mo=Morning; Mi=Midday; Af=Afternoon: C= Constantly

Results of occupants' ventilation and heating logbooks

Table 3- Ventilation habits

	General ventilation			Wet areas ventilation		
Dwelling	Hours	When	Frequency	Hours	When	Frequency
Un-insulated house winter	5,0	Morning	Daily	-	-	-
Un-insulated house summer	8,8	Morning	Daily	-	-	-
Insulated house winter	0,5	Afternoon	Dry days	-	-	-
Insulated + double glazing winter	4,2	Afternoon	Daily	8,9	Midday	Daily
Insulated + double glazing summer	3,7	Afternoon	Daily	14,5	Morning	Daily
La Haya apartment winter	0,2	Midday	Daily	-	-	-

The summary of the ventilation logbooks (Table 3) shows that habits vary considerably from one household to another. The most ventilated dwelling is the un-insulated house. This could possibly be due to a lack of knowledge of the heat losses inherent in over-ventilation or it could be that with no insulation and little heating there is little difference in temperature between internal and external spaces and therefore there is no reason not to ventilate. The dwelling with least active ventilation is the apartment in La Haya building. One explication could be that the apartment is the show-flat and being unoccupied is only ventilated by the sales staff once a day. However it could also be that additional ventilation is not necessary as there exists a fixed controlled background ventilation via tubes that pass through the walls.

The results of the heating and visitor logbooks (table 4) also show a variety of habits, however all but the new apartment in La Haya use sporadic rather than continual heating. The infrequency in the un-insulated house is in part due to the low occupation of this dwelling where its occupant spends much of the day at work; it is however likely that it also shows an example of fuel poverty. In the case of the La Haya apartment the heating is via an air-to-air heat pump with a thermostat. The system is therefore turned on all the time but is not always functioning.

Table 4- Heating habits and number of visitors.

	Heating			Wood burning cooker			Visitors		
Dwelling	Hour	When	Frequency	Hours	When	Frequency	N°	When	Frequency
Un-insulated house winter	0,3	Night	Infrequent	0,8	Afternoon	Infrequent	-	-	-
Un-insulated house summer	-	-	-	-	-	-	-	-	-
Insulated house Winter	5,6	Night	Daily	-	-	-	-	-	-
Insulated + double glazing Winter	4,1	Night	Daily	8,2	Midday	Daily	5,6	Afternoon	Daily
Insulated + double glazing summer	0,0	-	Never	5,4	Midday	Daily	3,6	-	Daily
La Haya winter	24,0	Always	Daily	-	-	-	-	-	-

These results start to form a picture of the varied behaviour of the occupants of dwellings in Temuco-Padre Las Casas, however it is clear that a greater number of owners and dwellings need to be included in a larger-scale project in order to really draw conclusions with a statistical value. The varying degree of success of gather data through the occupants' logbook also highlights the problems of voluntary participation with no direct reward, financial or otherwise. To obtain high quality results a large sample size is needed and some incentive should be offered.

Conclusions

The study clearly shows the positive impacts of improving the thermal proprieties of the building envelope, these being; reduced use of firewood and resulting emissions; improved hygrothermal comfort; and a greater environmental consciousness of the occupants. The latter should not be underestimated. The positive impacts of building refurbishment or the design of zero emission buildings, influence the community in a way that goes far beyond that possible through advertising campaigns or restrictions. When the surrounding neighbourhood is designed to an equally high standard, with quality circulation, meeting and play spaces, and sustainable landscaping, this effect can be enhanced. The refurbishment of existing dwellings also avoids the relocation of the occupants, allowing them to stay in central locations and maintain the local community. The embodied energy of the buildings is also reused.

In order for both refurbishment and new build low energy projects to achieve their aims training is also needed. Occupants must learn how to manage indoor temperature and humidity for achieving comfort (some of the owners had bought a thermometer for doing so). If new technologies or concepts such as mechanical ventilation, car-sharing or community stores are to be incorporated induction course must also be offered. Most importantly the occupants should be informed as to how, when and who to ask for help and take decisions together. For successful projects social organization is essential and has to be in place prior to embarking on the design process.

Some technical issues must also be addressed. Heating use is sporadic and not continual. If dwellings are to reduce infiltration rates through improve air-tightness, alternative ventilations must be considered to assure air quality and avoid high relative humidity. The study showed a wide variety of ventilation behaviour ranging from over-ventilation to insufficient. It would therefore appear that controlled ventilation with heat recovery must be designed, installed and verified in addition to training for occupants in its operation. At the same time indoor humidity production rates need to be substantially diminished. Kitchen and bathrooms have to be designed with special ventilation control. Drying space for laundry has to be considered in the design, with additional ventilation. These can be as either private or public spaces. As external temperatures can rise to over 35º C in summer months it is crucial to avoid overheating. Solar protection of glazed areas must therefore be designed to provide shade in summer months in order to minimize the greenhouse effect of double glazing and high insulation. Sufficient thermal mass must also be incorporated to mitigate high summer temperatures. It is better to have double aspect departments in order to have enhanced cross ventilation during summer months, better daylighting and avoid poorly orientated single aspect dwellings.

Armed with these conclusions, together with previously published work on the mixed use residential sustainable building (Whitman et al 2013) the authors have the basis for a design guide for energy efficient dwellings for Temuco-Padre Las Casas. Further funding is currently being sought to complete the guide and put it into practice. One step towards the construction of a sustainable future for Chile's contaminated cities.

References

IC (Instituto de la Construcción) (2008) *Determinación de línea base "anual" para la evaluacion de la inversion en eficiencia energetica en el sector residencial invierno 2007 – verano 2008.* Proyecto Fomento de la Eficiencia Energética (CNE/GTZ) Santiago de Chile.

INE (Instituto Nacional de Estadistica) (2012), *Resultados Preliminares Censo de Población y Vivienda 2012*, Santiago de Chile.

Minsegpres (Ministerio Secretaría General de la Presidencia) (2013) *Declara zona saturado por material particulado respirable MP10, como concentración de 24 horas, a las comunas de Temuco y Padre Las Casas.* Biblioteca del Congreso Nacional de Chile, Santiago de Chile.

MMA (Ministerio de Medio Ambiente) (2013) *Declara zona saturado por material particulado fino respirable MP2.5, como concentración diaria, a las comunas de Temuco y Padre Las Casas.* Biblioteca del Congreso Nacional de Chile, Santiago de Chile.

Ulloa, P. Contreras, G.C. and Collados, E. (2010) *Medidas costo-efectivas para reducer la contaminación del aire generada por la combustion de leña en ciudades del sur de Chile.* Ministerio del Medio Ambiente, Santiago de Chile.

Whitman, C.J., Armijo, G. and Roubelat, L. (2013) The mixed use residential building: A solution for Mediterranean Chilean cities declared saturated in terms of airborne Pollution. *19th CIB World Building Congress*, Brisbane.