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Environmental Comfort in the Living Heritage of the Chilean Araucanía: The Ruka Lafkenche and the Fogón Pehuenche.

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Abstract

Indigenous architecture's adaption to its climate and its use of local materials has attracted interest in the search for a sustainable built environment. In Chile surviving examples include the iconic *Ruka* Lafkenche and the little known *Fogón* Pehuenche. United by the world outlook of the Mapuche people, these two examples are located in different climates and as a result different construction systems have developed. This paper presents the results of a government funded research project, which studies their construction materials and techniques, and presents an evaluation of the previously unstudied internal environmental comfort. The results show that materials used are low carbon and locally resourced; open hearths achieve a comfortable globe temperature for those gathered around them; however they have little effect on the dry-bulb temperature and produce large quantities of ultrafine particulate matter. This poor indoor air quality presents a challenge for achieving internal environmental comfort. However the approach to the use of low impact, local, biodegradable materials is exemplary and provides valuable indications of how a sustainable and appropriate architecture might be developed for the Chilean Araucanía region.

Keywords: Indigenous architecture, environmental comfort, air quality, sustainable materials, Chile

1 Introduction

In today's globalized world, expressions of locality are becoming increasingly valued. According to official statistics, 40% of the 3,070,000 foreign tourists arriving in Chile in 2011 cited culture and heritage as their principal motivation for visiting (Bertin, 2012). Statistics for Chile's Araucanía region show that in the same year more than 80% of foreign tourists and 40% of national tourists requested information on activities specifically related to the region's indigenous Mapuche people (Sernatur 2012). In this context the Mapuche dwelling or *ruka* has become the icon for the international promotion of the region (Sernatur 2012). For centuries the *ruka* has formed an important part of Mapuche cultural identity; a symbol and tradition that exists until today. However within Chile the architecture of its original inhabitants receives little recognition. Wainsberg (1978) in his book "*En torno a la historia de la arquitectura Chilena*" begins the history of Chilean architecture with the colonial architecture of the Spanish conquistadores, whilst Gross (1978) in "*Arquitectura en Chile*" dedicates only 3 pages to the Mapuche *ruka* illustrating only the most well known typology, that of the *Lafkenche* coastal tribes. These omissions have been to some extent rectified with the publication of the Ministry of Public Works Mapuche design guide for public buildings and spaces (MOP 2003). The guide sets out the world view of the Mapuche and specifies the distinct styles, forms and spatial planning of their constructions with the aim to integrate this information in the design of public infrastructure intended for their use. The guide however focuses on formal aspects, thereby leaving an important characteristic of Mapuche architecture unexplored, namely its adaptation to climatic and geographic conditions in order to provide comfort and habitability which has been developed over centuries.

1.1 The Study of Vernacular and Indigenous Architecture: A Global Perspective

In the 19th century the study of vernacular and indigenous architecture in Europe focused on the search for a national style and identity, whilst the study of oriental indigenous architecture and that of the southern hemisphere was purely anthropological (Arboleda 2006). In the 20th Century, architects such as Adolf Loos, Le Corbusier and Frank Lloyd Wright referred to vernacular architecture in their theories on form and composition, whilst the exhibition "*Architecture without Architects*" at the Museum of Modern Art in New York and the accompanying book (Rudofsky, B. 1968), highlighted the aesthetic qualities of the vernacular. Towards the end of the 1960s research and publications such as "*Shelter and Society*" (Oliver 1969) and "House Form and Culture" (Rapoport 1969) began to focus on the cultural and social aspects of vernacular and indigenous architecture. Since the 1990s academics (Ubbelohde 1991, Cook 1996, Zhai & Previtali 2009, Huang & Lui 2010, Foruzanmehr & Vellinga 2011) have studied the performance of vernacular and indigenous architecture within the context of sustainability and the search for a low energy architecture with less environmental impacts. Vernacular architecture is now appreciated for its environmental principals and bioclimatic concepts. In this way its study is useful for those engaged in the design of the built environment (Rapoport 2006). However the sustainability of vernacular and indigenous architecture has been idealized (Arboleda 2006) and it is therefore necessary to obtain empirical measurements of its performance in use to allow the application of its advantages and the avoidance of its drawbacks.

1.2 The Mapuche *rukas*

Table 1. Characteristics of the *rukas* of the different branches of the Mapuche people.

	Plan form	Roof material	Wall material	Door location	Windows
Picunches People of the North	Rectangular or oval	Thatch	Wattle and daub (*quincha*) or vertical boards	One facing east	No
Lafkenche People of the sea	Oval or circular	Thatch	Straw or reeds	One facing east	No
Nagche People of the plains	Oval	Thatch	Vertical boards or posts	One facing east	No
Pehuenche People of the Pehuen (fruit of the Araucaria tree)	Rectangular or circular	Hollowed tree trunks	Hollowed tree trunks	One facing east	No
Williche People of the south	Rectangular	Thatch	Horizontal boards	Two one facing east the other west	Yes

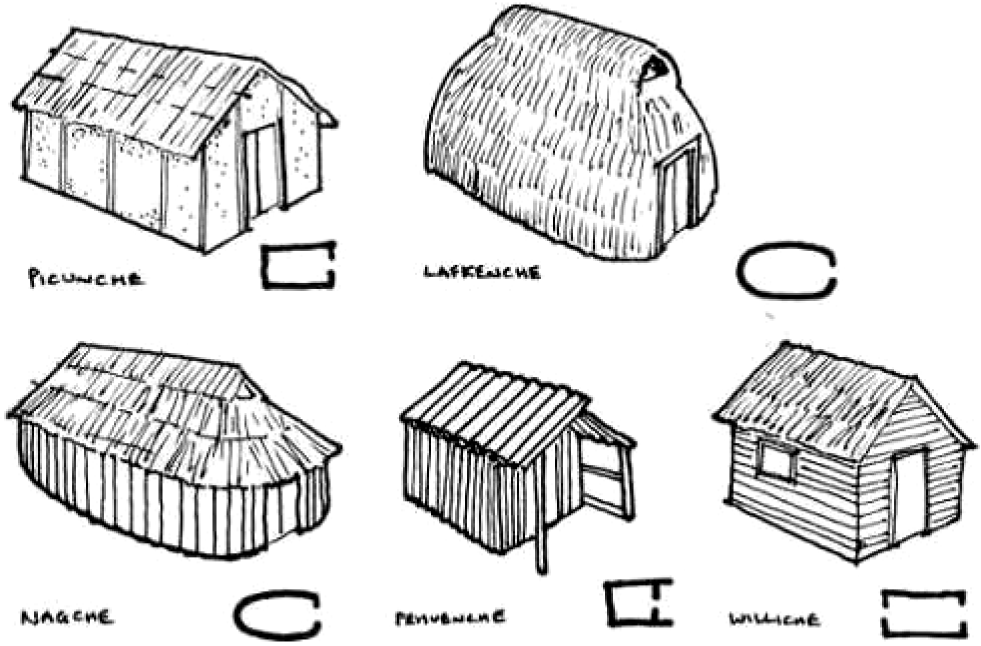


Figure 1: The *rukas* of the different branches of the Mapuche people. *Source*: Diagram by C. Whitman

The *ruka* of the Mapuche (People of the Earth *mapu*-earth, *che*-people) is the most representative architectural element of the Mapuche world. It symbolizes the *nag mapu,* the domestication of the natural environment, the most important space for the meeting and participation of the community (MOP 2003). A fundamental Mapuche concept is the temporality of their constructions; they are ephemeral, made of only natural biodegradable materials with little elaboration. The form and materials of the *rukas* of the different branches of the Mapuche people (Table 1 & fig.1) depends on the climate and the materials locally available. This paper presents a study of the rukas of just two branches, the Lafkenche and the Pehuenche.

1.2.1 The Lafkenche ruka

The *rukas* of the Lafkenche or People of the Sea are built on the tops of the low coastal hills. These raised locations provide good visibility to avoid surprises from enemies and protection from flooding (Otero 2006). The construction of a *ruka* is a communal task or *mingaco.* Following the completion of the main structure the owner offers the workers a meal with meat, bread and *mudai* or *chicha,* alcoholic drinks made from fermented wheat, corn, apples or pine nuts. Another meal is offered following the completion of the thatching. It is said that between the completion of the structure and thatching sufficient time is always left in order to prepare sufficient meat and *chicha* [Coña 2002]. The *ruka encolihuada* predates the contemporary *ruka*. This consisted of a conical structure constructed around a central vertical pole (Coña 2002). Today the *rukas* are oval in plan with a primary structure of tree trunks. Forked trunks or *taras* form vertical posts supporting horizontal beams culminating in the ridge beam or *kuikuipani* (Coña 2002) (fig.2). This primary structure supports a secondary structure of thinner trunks and branches which is in turn thatched with ratonera grass (*Hierochloe utriculata*), sedge (*Schoenoplectus californicus*) or tree suckers. The thatch is placed starting at the bottom, working upwards so that the second row overlaps and covers most of the first. “Immediately below each end of the ridge beam they leave corresponding openings, these holes of the house allow the smoke to escape and provide roosts for the chickens” (Coña 2002). There is one doorway which is orientated towards the East, towards the rising sun. The prevailing winds are from the South and from the North in winter. The orientation of the openings and doors provide protection from these winds. Coña claims that historically there was no need to close this opening as robberies were unheard of and that closing doors were only introduced with the arrival of the Spanish to prevent theft.

Traditionally there were no subdivisions within the *ruka*, the space being organized around the open hearth. In contemporary constructions a low division made of local bamboo has been introduced to divide the sleeping and living areas. The smoke and soot from the open fire plays a fundamental role in the preservation of the construction materials, impregnating both the timber and the thatch.

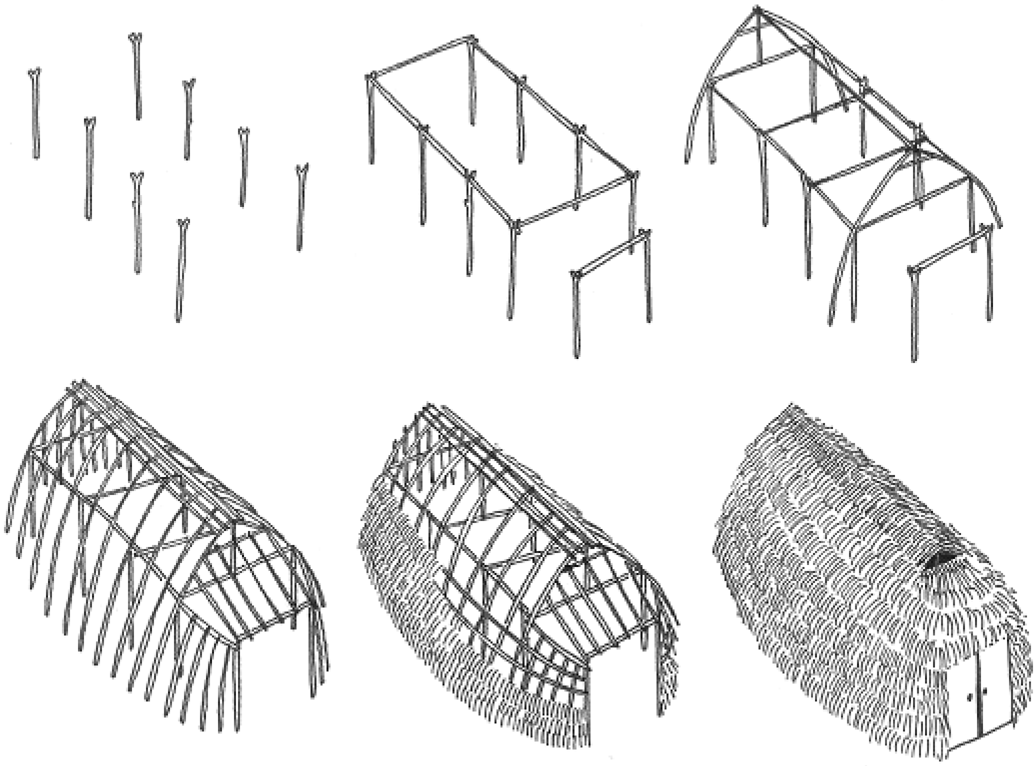


Figure 2: Construction sequence of a Lafkenche *ruka*. *Source*: Diagram by C. Whitman

1.2.2 The *rukas* and *fogones* of the Pehuenche

The *rukas* and *fogones* of the Pehuenche are very different from those of the other Mapuche people and little written information exists about them. They are constructed from straight hollowed half tree trunks in the form of canoes. These canoes o *wampos* are placed like clay roof tiles to form walls and roofs. Those used for the roof have brackets carved at their bases so that they rest on the horizontal beam of the post and beam structure (Fig.3). When well constructed the placement of the *wampos* avoid gaps between one element and the other. In the case that gaps occur these are infilled with smaller timbers. Traditionally the logs were split along the grain using wedges of the hardwoods meli (A*momyrtus meli)* or luma (A*momyrtus luma*) and mallets of the same timbers (Otero 2006).

Figure 3. Detail of construction of Pehuenche *fogón*.

1.3 Objectives

This paper presents the results of the government funded project Fondart N° 1685 "*Confort ambiental en el patrimonio vivo de la Araucanía: La ruka Lafkenche y el fogón Pehuenche*" (Environmental comfort in the living heritage of the Araucanía: The Lafkenche Ruka and the Pehuenche Fogón) which studied the construction techniques, materials, use and environmental comfort of the *rukas* Lafkenche and Pehuenche located in Llaguepulli and Quinquén respectively, both in the Araucanía Region of Southern Chile.

2 Methodology

A bibliographic study was made of Mapuche architecture prior to study trips to the Lafkenche community Llaguepulli by the coast and the Pehuenche community of Quinquén in the Andes. The first study trip was undertaken 20th-25th July 2013 during the Chilean winter. The second study trip took place 2nd-7th January 2014 during the Chilean summer. Measurements were made of dry-bulb air temperature, relative humidity and concentrations of CO2 with a combined digital hygrothermometer/CO_2 meter Extech CO200; black globe temperature with a digital black globe thermometer Sper Scientific 800037; radiant surface temperature with an infrared thermometer Raytek MinitempMT6; thermal imaging with a thermal imaging camera Fluke TiR; natural daylighting with a digital light meter Hibok 35; and air quality in the form of concentrations of ultra-fine particulate matter with a P-Trak 8525. The results of these measurements are presented below.

In addition to specific in situ measurements, wireless hygrothermic data loggers iButton DS1923-Hygrochron were used to take continual measurements of dry-bulb air temperature and relative humidity. In Llaguepulli, to determine differences in air temperature according to distance from the open fire, data loggers were hung 1.7m above finished floor level, one 1m in plan from the fire and another at the furthest point from the fire. An additional data logger was installed externally, protected from direct sunlight, wind and rain. Concurrent continual measurements of black globe temperature were also taken for a period of 24 hours with readings at hourly intervals (Fig 7).

Following these measurements, further measurements were undertaken to determine if the interior spaces can be defined as homogeneous or heterogeneous with regards to the horizontal stratification of temperatures as defined by the International Standard ISO 7726:1998 Ergonomics of the thermal environment - Instruments for measuring physical quantities (CEN 2002). Following the Standard, data loggers were installed at 0.1m, 1.1m and 1.7m above finished floor level, 2m in plan from the open fire. Measurements were taken for a period of 24 hours at 5 minute intervals (Fig 8).

For the long term continuous measurements data loggers were installed 2m in plan from the open fire at three heights, 0.1m, 1.1m and 1.7m. In addition sensors were installed externally, in a second *ruka* and an adjacent timber cabin at a height of 1.1m. The sensors were left for a period of 3 months, 22nd July- 1st October 2013. The results (figures 12-15) are presented in the form of psychrometric charts (GIVONI 1998).

In January 2014 summer conditions were monitored with the sensors reinstalled in the same positions. Measurements were recorded for a period of 48 hours at an interval of 5 minutes (figure 9). The sensors were then reinstalled for hourly measurements 4th January- 26th February 2014 (Figs 16-19).

In Quinquén continuous measurements were undertaken of dry-bulb temperature and relative humidity with sensors installed 2m in plan from the open fire at a height of 0.1m, 1.1m and 1.7m. The first measurements were for a period of 22 hours at 5 minutes intervals (Fig. 25). These were followed by hourly measurements 25th July - 30th September 2013 (Figs. 30&31) and 1st November 2013- 6th January 2014 (figures 26&27).

2.1 Interviews with owners

Interviews were conducted with each of the owners regarding construction, use and their perceptions of environmental comfort within the *rukas*. It is important to stress that these perceptions are based primarily on their memories of a time when they lived in *rukas*. Continual occupation of the *rukas* in this region ended during the 1990s when government subsidies were made available for the construction of social housing. Today most people do not live in their *rukas*, reserving them for special events, meetings and celebrations or for visitors.

3 Data and Analyses

3.1 Data and Analyses of *rukas* Lafkenche

3.1.1 Climatic Conditions, Llaguepulli, Lago Budi 38° 56'S, longitude 73° 16´W

According to the Chilean Standard NCh1079. Of 2008 (INN 2008) the climate of coastal Araucanía Region is classified as "Southern Coastal" a "zone of maritime climate, rainy. Long winters. Ground and environment saline and humid. Strong winds mainly westerly. Robust vegetation. Temperature temperate to cold." The average temperatures are presented in Table 2.

Table 2: Temperatures of Coastal Araucanía Region [Uribe et al. 2012]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Oct	Dec
T (ºC)	16	15,5	14	12	10	8,5	7,9	8,3	11,8	9,8	13,8	15,4
Tmax (ºC)	21,9	21,3	19,4	16,8	14	11,9	11,1	11,8	13,7	16,4	19,1	21,1
Tmin (ºC)	10,2	9,7	8,7	6	7,3	5	4,6	4,9	5,8	7,1	8,5	9,6

3.1.2 Rukas Lafkenche, Ina Lewfu (Lake Shore)

Sr. Ramón 2° Lefio Maripan and his wife Sra. Selma Caniuñir own two *rukas*, *ruka grande* (figs. 4&5) and *ruka chica* built 6 and 3 years ago respectively, in which they offer tourist accommodation. Don Ramón was born and raised in a *ruka* with his 12 brothers and sisters. There existed no internal divisions except for two compartments constructed on either side of the door, one for wheat and the other for potatoes. He remembers the *ruka* as warm and cosy in winter and neither cold nor hot in summer. When his mother first received government funding for a zinc clad house the family continued to live in the *ruka* using the zinc house only for sleeping. In summer they would go to *ruka* to escape the heat of the zinc house. Don Ramón did however comment that the zinc house changed their way of life, there was no smoke, but the *ruka* was always warm.

Figure 4: Author and Sra. Selma Caniuñir outside the *ruka grande*. Figure 5. Interior of the *ruka grande*.

3.1.2.1 Specific in situ measurements: Ina Lewfu

Table 3: Specific measurements Ina Lewfu 20, 21 and 23 July 2013. (f) Fire lit, (u) Fire unlit.

Date 2013	Hour	Location	Dry-bulb temperature (°C)	Black Globe Temperature (°C)	Radiant surface temperature (°C)						Relative humidity (%)	CO_2 (ppm)	Ultra fine particulate material (particles/cm^3)
					North	East	South	West	Ceiling	Floor			
20/07	15:50	Exterior	8.3	7.7	-	-	-	-	-	-	55.0	493	-
		Ruka chica (f)	11.2	19.8	10.4	10.0	9.6	11.2	16.6	9.8	54.3	570	360,000
	17:00	Exterior	8	-	-	-	-	-	-	-	55.0	494	7000
		Ruka chica (f)	13.5	24.1	10.2	12.4	10.0	11.2	15.2	10.0	46.5	714	>500,000
	18:50	Exterior	5.5	-	-	-	-	-	-	-	65.3	495	-
		Ruka chica (f)	12.5	25.0	12.0	14.0	13.0	12.6	19.2	12.2	53.2	704	>500,000
21/07	07:50	Exterior	1.1	-	-	-	-	-	-	-	85.0	505	3550
		Ruka chica (u)	2.6	2.2	2.4	1.4	2.4	2.4	2.2	4.8	75.0	508	3400
	12:40	Exterior	6.6	-	-	-	-	-	-	-	58.6	-	-
		Ruka chica (f)	11.5	20.6	9.0	10.6	10.8	9.8	15.0	8.8	56.3	626	>500,000
	13:20	Exterior	7.4	-	-	-	-	-	-	-	50.0	505	7420
		Ruka grande (f)	11.2	18.5	5.8	8.2	8.4	4.8	23.6	8.4	50.6	678	358,860
	16:20	Exterior	7.2	-	-	-	-	-	-	-	46.4	491	-
		Ruka grande (f)	10.4	17.8	10.0	11.0	13.4	7.6	20.0	10.4	53.2	557	-
23/07	10:15	Exterior	7.0	-	-	-	-	-	-	-	80.2	524	-
		Cabin (f)	11.0	12.6	8.8	10.6	10.4	10.2	11.8	10.4	67.5	926	18,100

The winter results (Table 3) show that the internal dry-bulb temperatures are on average 4°C higher than the external temperature. Even in the morning prior to lighting the fire the temperature was 1.5°C higher. Whilst dry-bulb temperatures are well below the comfort zone (Givoni 1998), the black globe temperatures fall consistently within the zone when the open hearth is lit. Wall radiant surface temperatures are close to the dry-bulb temperatures as would be expected from a low thermal mass structure, whilst that of the mass of the earthen floor is higher and that of the ceiling shows a horizontal stratification of the heat. Concentrations of CO2 show there is sufficient ventilation, however concentrations of ultra-fine particles are extremely high.

Table 4: Specific measurements Ina Lewfu 2, 3 and 4 January 2014. (f) Fire lit, (u) Fire unlit.

Date 2014	Hour	Location	Dry-bulb temperature (°C)	Black Globe Temperature (°C)	Radiant surface temperature (°C)						Relative humidity (%)	CO_2 (ppm)	Ultra fine particulate material (particles/cm^3)
					North	East	South	West	Ceiling	Floor			
02/01	17:35	Exterior	14.4	14.9	-	-	-	-	-	-	55.8	487	440
		Ruka chica (u)	16.1	15.9	-	-	-	-	-	-	51.7	491	995
03/01	10:40	Exterior	14.4	-	-	-	-	-	-	-	51.7	472	4470
		Ruka chica (u)	14.8	14.8	12.9	13.9	11.2	12.0	13.3	10.8	54.0	485	3450
	12:20	Exterior	14.8	29.2	-	-	-	-	-	-	47.9	486	4300
		Ruka chica (u)	15.9	15.5	13.2	14.0	11.9	12.3	13.9	12.3	48.6	500	5170
	15:30	Exterior	15.7	-	-	-	-	-	-	-	49.1	484	2140
		Ruka chica (u)	16.2	15.8	14.3	14.4	13.4	16.4	14.3	11.7	51.4	502	1620
		Ruka grande (u)	16.0	-	13.0	13.7	12.8	12.8	13.9	11.6	50.7	499	1040
		Cabin (u)	18.8	-	15.7	17.8	16.9	20.5	21.2	16.3	50.4	520	2900
04/01	10:10	Exterior	20.0	-	-	-	-	-	-	-	60.8	495	500
		Ruka chica (u)	18.2	17.1	14.1	15.3	14.3	14.2	17.8	12.7	62.8	516	375
		Ruka grande (u)	17.1	-	13.5	15.0	13.6	14.0	16.7	12.0	66.0	511	2010
		Cabin (u)	19.0	-	16.1	14.9	15.5	14.6	22.3	14.1	48.7	517	1030
	12:40	Exterior	20.9	-	-	-	-	-	-	-	68.2	478	6480
		Ruka chica (u)	20.5	18.4	16.7	17.0	16.5	18.0	17.0	15.2	65.3	492	4890
		Ruka grande (u)	18.7	-	15.3	17.0	15.8	16.0	19.8	13.1	68.6	497	5420
		Cabin (u)	21.5	-	19.9	20.3	20.0	19.7	24.8	19.0	60.0	496	6300
	15:30	Exterior	20.8	-	-	-	-	-	-	-	64.7	496	359
		Ruka chica (u)	19.9	19.4	18.2	18.0	17.8	20.8	17.3	15.7	67.9	502	337
		Ruka grande (u)	19.5	-	17.0	17.6	17.0	17.0	18.9	14.4	69.1	499	1310
		Cabin (u)	22.7	-	22.9	22.4	22.0	26.0	28.0	22.0	60.3	496	6510

The summer results (Table 4) show internal dry-bulb temperatures of the *rukas* equal or inferior to external temperatures, whilst those of the timber cabin are superior but do not indicate a problem with overheating. Only the radiant surface temperature of the ceiling of the cabin on the 4th of January hints at the potential for overheating. Thermal imaging of the ceiling showed irregular surface temperatures suggesting non-continuous insulation. Internal concentrations of ultra-fine particles are similar to external levels when the open hearths are unlit confirming that these are the primary source of this contamination.

		0,3%	0,2%	0,2%	0,2%	0,1%	0,1%							
		0,3%	0,3%	0,2%	0,2%	0,2%	0,4%	0,5%						
	0,2%	0,3%	0,3%	0,3%	0,3%	0,3%	0,6%	1,0%	1,9%	2,9%	2,3%	1,7%		
0,1%	0,2%	0,3%	0,3%	0,3%	0,3%	0,3%	1,5%	2,6%	3,7%	4,7%	5,1%	5,6%	8,3%	11,9%
0,3%	0,3%	0,3%	0,3%	0,3%	0,3%	0,3%	2,3%	4,3%	5,4%	6,6%	8,0%	9,4%	16,6%	23,7%
0,3%	0,3%	0,3%	0,3%	0,3%	0,3%	0,3%	2,7%	5,0%	7,0%	9,0%	10,4% hearth	11,9%	19,9%	28,0%
0,3%	0,3%	0,3%	0,3%	0,3%	0,3%	0,4%	3,0%	5,7%	8,6%	11,4%	12,9%	14,3%	23,3%	32,3%
0,2%	0,3%	0,3%	0,3%	0,3%	0,4%	0,5%	2,5%	4,5%	6,7%	9,0%	10,6%	12,1%	21,3%	30,4%
0,2%	0,3%	0,4%	0,3%	0,3%	0,5%	0,7%	1,9%	3,2%	4,9%	6,6%	8,3%	10,0%	19,3%	28,6%
0,1%	0,2%	0,3%	0,3%	0,3%	0,4%	0,5%	1,3%	2,0%	2,9%	3,8%	4,5%	5,2%	9,6%	14,3%
	0,1%	0,3%	0,3%	0,3%	0,3%	0,4%	0,6%	0,9%	0,9%	1,0%	0,7%	0,3%		
		0,3%	0,3%	0,3%	0,3%	0,3%	0,4%	0,4%						
		0,3%	0,3%	0,3%	0,2%	0,2%	0,1%							

Figure 6: Distribution of daylight factor within the *ruka chica* 21 July 2014

Natural daylight (Fig.6) is concentrated around the open door which corresponds to the area around the open hearth. The contribution of the roof openings is negligible.

3.1.2.2 Continual Measurements: Ina Lewfu

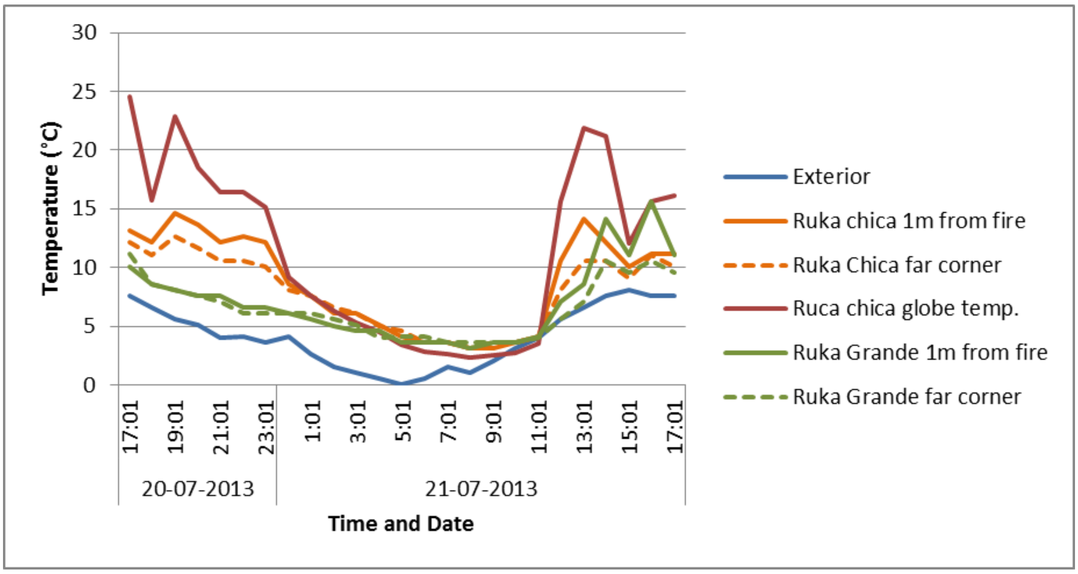


Figure 7: Simultaneous measurments of dry-bulb temperature and globe temperature at different points in plan. Ina Lewfu 20th-21st July 2013 (Austral Winter)

When the open hearth is lit in the *ruka chica* its radiant heat is clearly recorded by the black globe temperature (Fig. 7), the difference in dry-bulb temperature according to distance from the hearth reaches a maximum of 0.5°C and the difference with the external dry-bulb temperature a maximum of 7°C. Only the globe temperature acheives comfort levels.

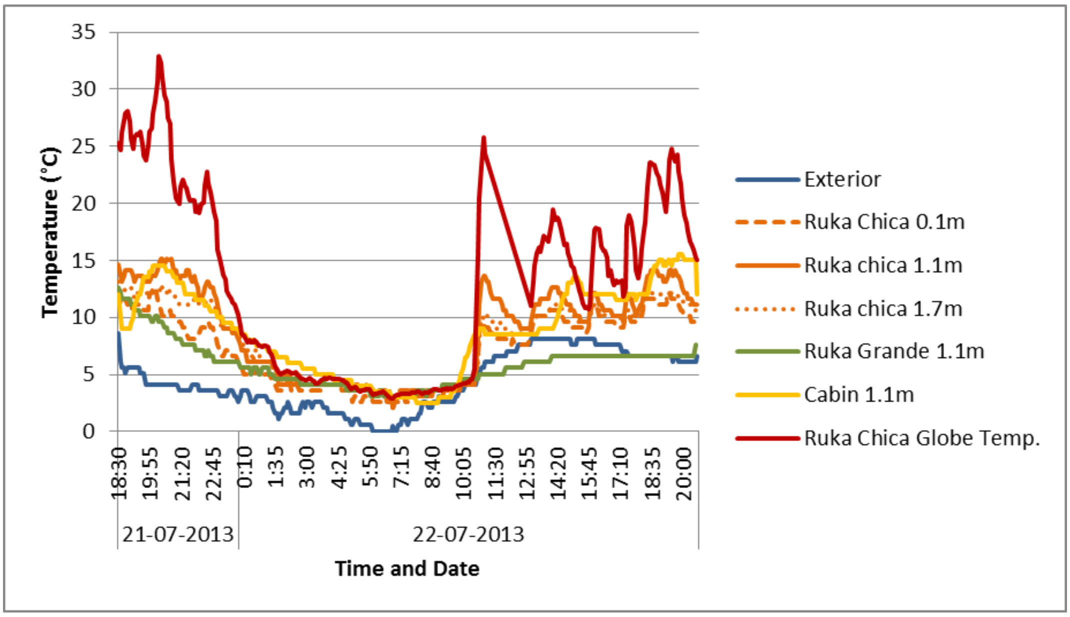


Figure 8: Simultaneous measurments of dry-bulb temperature and globe temperature. Ina Lewfu 21st-22nd July 2013 (Austral Winter)

Again the radiant heat of the hearth is clearly illustrated by the globe temperature (Fig.8) which at one point even exceeded the comfort zone. The dry-bulb temperature is highest at 1.1m above floor level reaching 15.1°C, 4.5°C higher than the dry-bulb temperature at 0.1m, 2.5°C higher than that at 1.7m and 11°C higher than the outdoor temperature. This indicates horizontal thermal stratification and that the space should be considered as heterogeneous for thermal measurments according to ISO 7726:1998 (CEN 2002). The indoor temperature of the cabin is similar to that of the *ruka chica*. The open hearth in the ruka grande was not lit on the 22nd resulting in temperatures lower than the exterior.

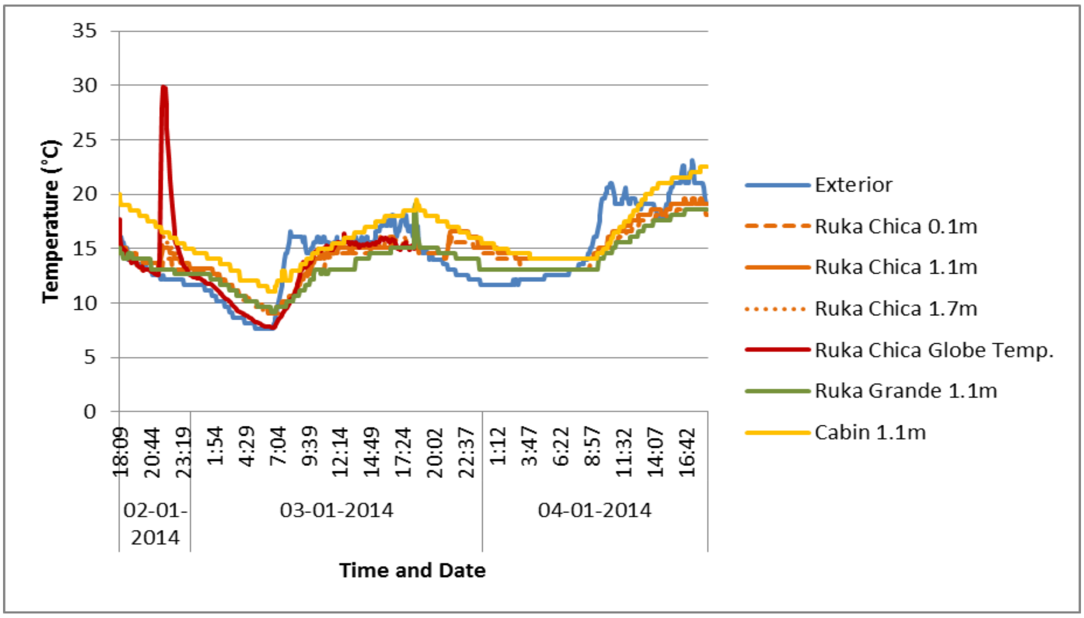


Figure 9: Simultaneous measurments of dry-bulb temperature and globe temperature. Ina Lewfu 2nd -4th January 2014 (Summer)

In summer the results (Fig. 9) show little horizontal stratification with the dry-bulb temperatures at 1.1m and 1.7 identical, between 1°C and 0.5°C higher than that at

0.1m. Only when the open hearth is lit do the temperatures at 1.1m and 1.7m diverge achieving a 1°C difference between the two, whilst the globe temperature rises to almost 30°C. Internal temperatures in the rukas are more stable than both the external and the interior temperature of the timber cabin.

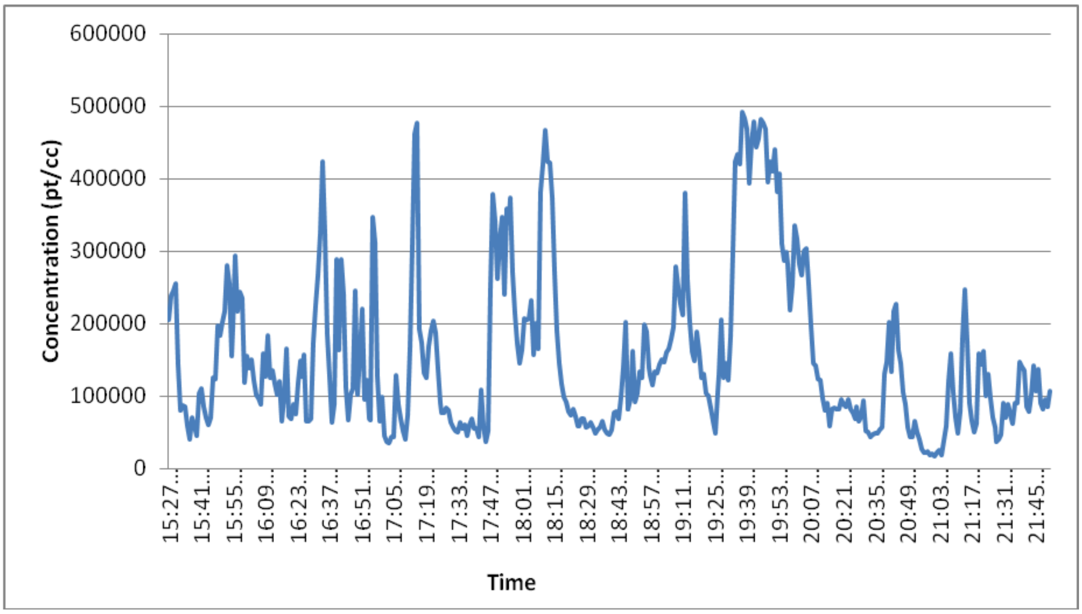


Figure 10: Measurements of concentration of ultra fine particulate matter in the ruka chica, Ina Lewfu 22nd July 2013 (Austral Winter) with open hearth lit.

The results (Fig.10) show high concentrations of ultra-fine particulate matter with peaks of almost 500,000 particles per cubic metre (pt/cc) and an average of 154,000 pt/cc over the 6 hour period. The levels decrease after 20:00 when the occupants go to bed and no further firewood is added.

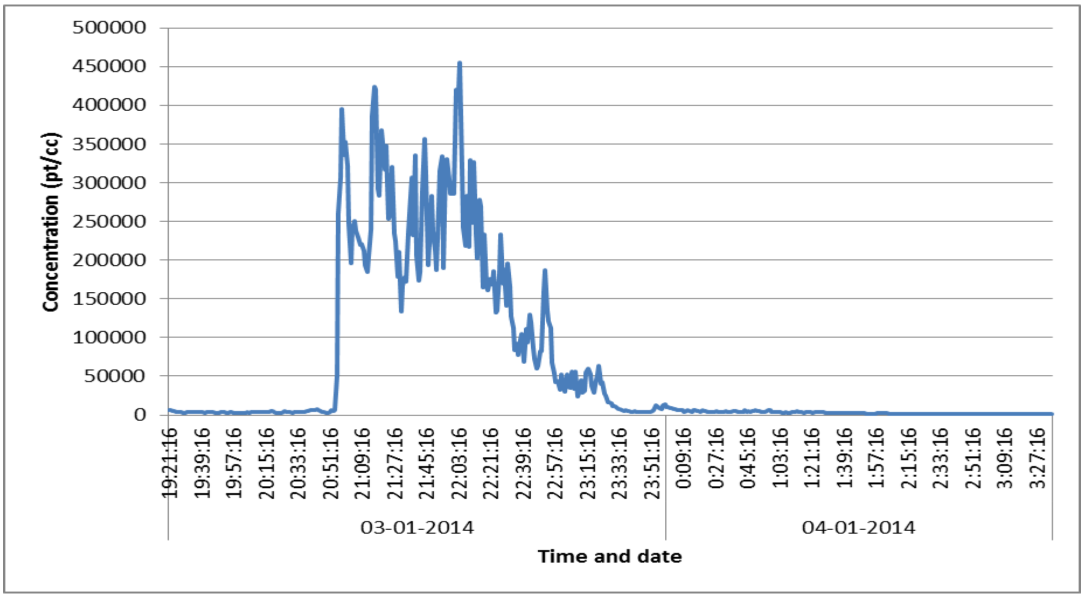
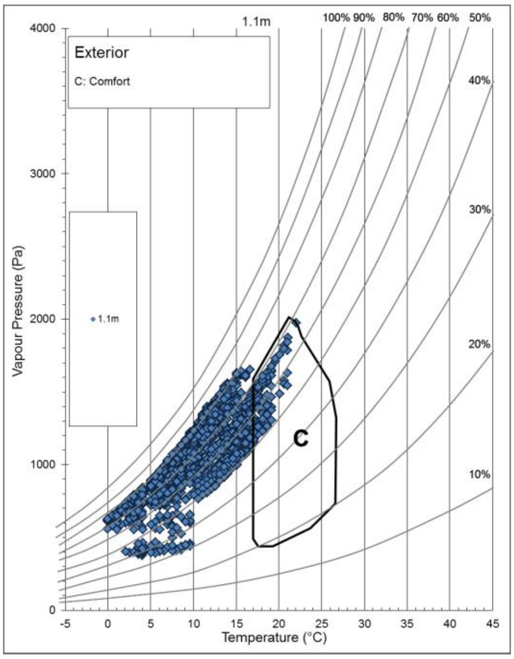


Figure 11: Measurements of concentration of ultra fine particulate matter in the ruka chica, Ina Lewfu 3rd-4th January (Austral Summer).

This graph (Fig. 11) graphically illustrates the impact of igniting the open hearth on the concentration of ultra-fine particulate mater, with concentrations rising to 100 times the background level in only three minutes.



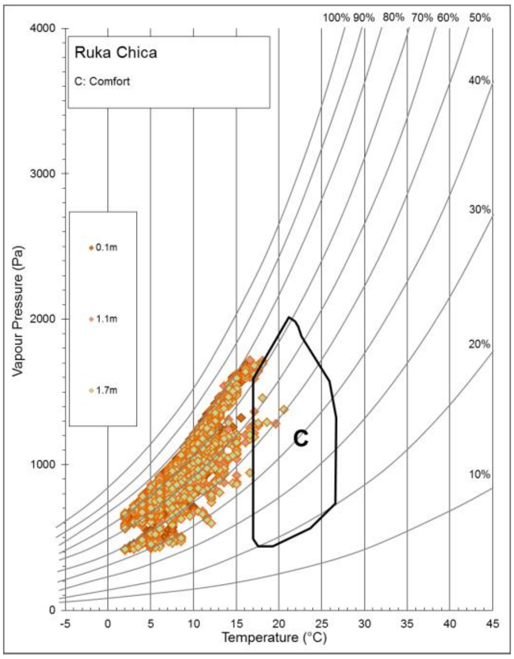
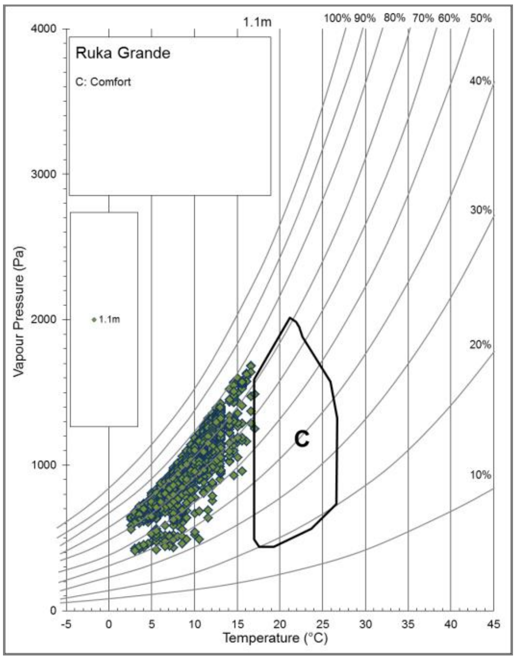


Figure 12 & Figure 13: Psychrometric charts showing temperature and relative humidity of the air externally and in the *ruka chica* from July to September 2013



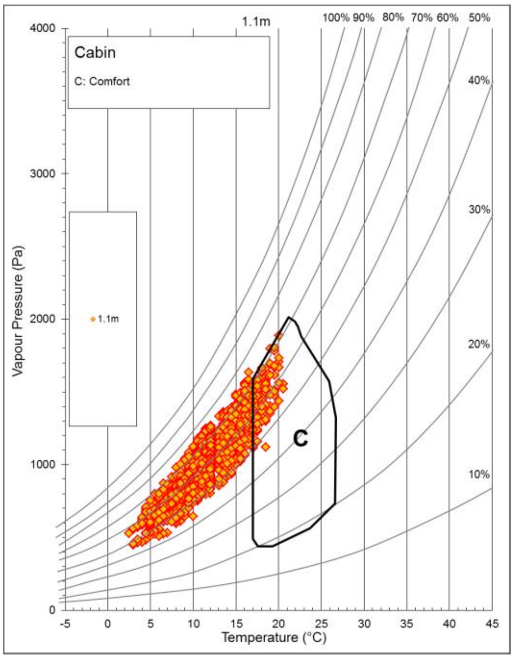
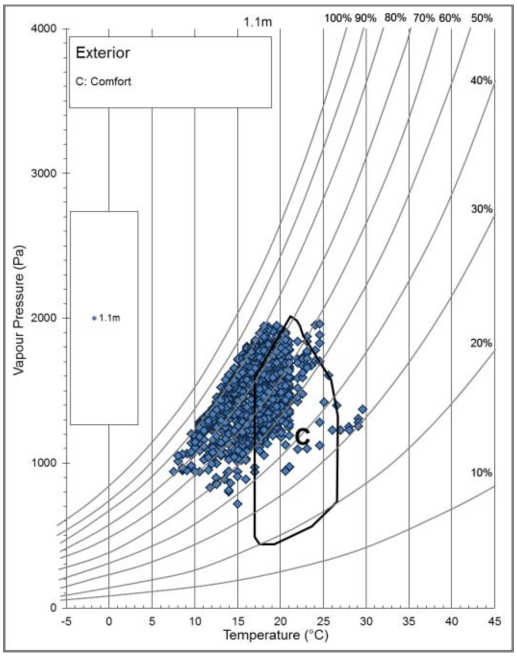


Figure 14 & Figure 15: Psychrometric charts showing temperature and relative humidity of the air in the *ruka grande* and timber cabin from July - September 2013.

The results (Figs. 12-15) show that in winter neither *ruka* achieves hygrothermal comfort (Givoni 1998) except on 12 isolated occasions. For 6% of the time external conditions are more favourable than interior. The *rukas* do however provide protection from the lowest temperatures maintaining 2.5°C, the same as the timber cabin whilst external temperatures drop to 0°C.



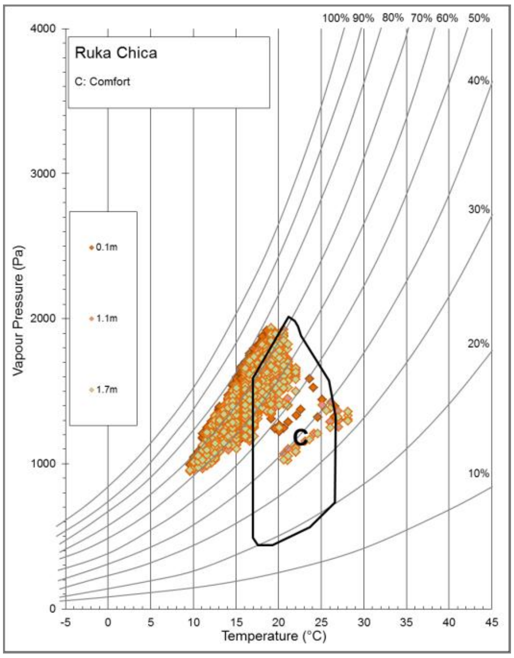
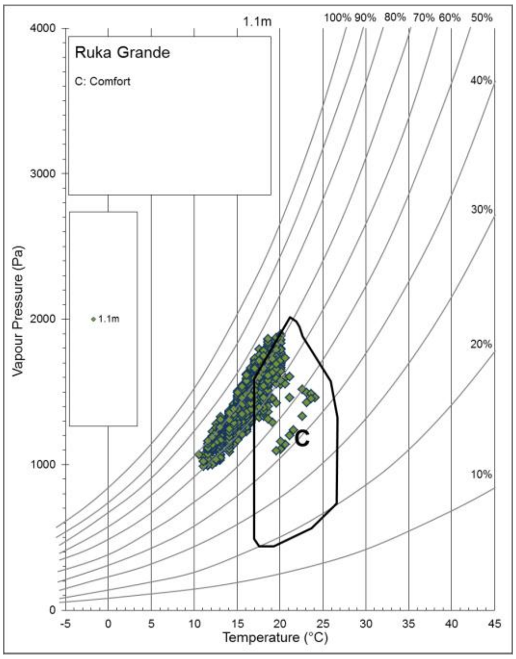


Figure 16 & Figure 17: Psychrometric charts showing temperature and relative humidity of the air externally and in the *ruka chica* from 4th January to 26th February 2014 (Austral Summer).



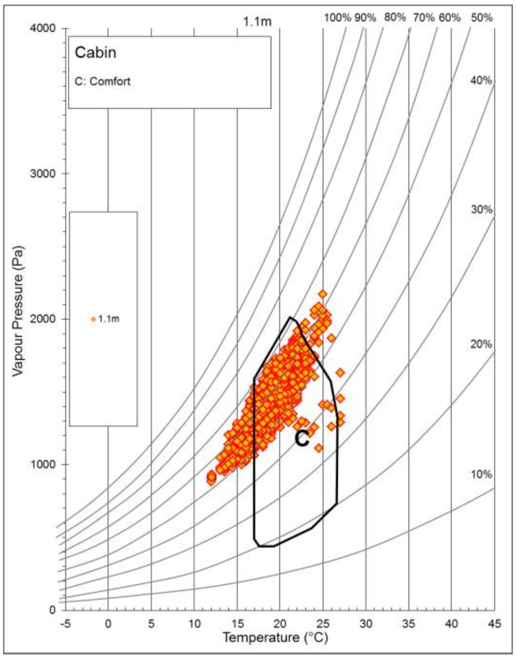


Figure 18 & Figure 19: Psychrometric charts showing temperature and relative humidity of the air in the *ruka grande* and timber cabin from 4th January to 26th February 2014 (Austral Summer)

The hourly summer measurements (Figs 16-19) show that temperatures in both *rukas* are similar to those externally, except for the extremes, where internal temperatures remain 2°C higher at the lower extreme and in general 3.5°C lower at the higher. Overheating in the *ruka* Chica is only experienced on one day when external temperatures reach 30°, whereas some overheating is experienced in the timber cabin. This corroborates the interviewee's opinion that the *rukas* are cooler in the summer than the new timber, zinc roofed houses. In general the relative humidity is high both internally and externally.

3.1.3 *Ruka* Lafkenche, Ad Lewfu (Lake View)

The family Painefil own 3 *rukas* (Figs 20&21), offering tourist accomodation, meetings spaces and craftwork. The daughter of the family Srta. Nadia Painefil was interviewed. Up until the early 1990s Nadia lived in a *ruka* until the age of 5 with her parents and 3 siblings. According to Nadia the *ruka* was comfortable both in winter and summer. She noted however that "the body becomes acustomed to the cold" and that in winter the family would always gather around the fire drinking maté. This time spent together around the fire is something that is missing today with the modern houses, in addition in summer the modern houses can overheat but the *rukas* don't.

Specific in situ measurements in winter showed internal dry-bulb temperatures equal to external temperatures when the hearth was unlit.

Figure 20: Srta. Nadia Painefil outside the *ruka* Ad Lewfu. Figure 21. Sr. Pablo Pablo Calfuqueo Lefío outside the *ruka* of Ad Mapulawen.

3.1.4 *Ruka* Lafkenche Mapulawen (Medicinal Garden)

The Calfuqueo family owns two *rukas* that they use for meetings and for receiving visitors to their medicinal herb garden. The son Sr. Pablo Calfuqueo Lefío was interviewed; he has been an important force behind the development of tourism as an alternative economic generator for the community. Pablo was born and grew up in a *ruka* until the age of 12. There were no divisions in the *ruka* except for pens for small fowl on either side of the door. The thermal sensation was one of comfort both in summer and in winter. Pablo noted that the *rukas* of his childhood were better insulated and that the thick layer of soot that built up helped seal the walls and further insulate. The lack of artificial lighting was not a problem as work activities were governed by the sunlight. The evenings were spent gathered around the open fire. Prior to 2000 all the *rukas* had disappeared from the community. The first new *rukas* were built at first to attract tourists, however in the last few years families have started to build their own new *rukas* for their own use for special occasions and family gatherings.

Specific in situ measurements in winter showed an internal dry-bulb temperature of 12.1°C with the hearth lit, 4.3°C higher than the external temperature.

3.2 Data and Analyses of *rukas* Pehuenche

3.2.1 Climatic Conditions Quinquén, Lago Galletue, alt. 1151m above sea level, 38° 40’S, 71° 17´W

According to the Chilean Standard NCh 1079. Of 2008, the climate of the Andean zone of the Araucanía Region is classified as “Andean”, a zone made up of many subzones currently little studied given the low population density. In general the zone has a dry atmosphere with large diurnal temperature oscillations. Blizzards and snow in winter. High altitude vegetation. High percentage of ultraviolet in the solar radiation. In general the conditions are severe (INN 2008). The temperatures for the border crossing located 20km from Quinquén are presented in Table 5.

Table 5: Average, Maximum and Minimum Temperatures Liucura [Dirección de Aguas 2012]

VARIABLE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Oct	Dec
T (ºC)	26,1	24,3	23,3	18,6	14,0	9,1	8,1	8,8	13,7	16,7	18,9	23,9
Tmax (ºC)	15,4	14,6	13,2	9,7	6,5	3,1	1,1	1,9	6,4	8,7	9,9	13,7
Tmin (ºC)	4,7	5,0	3,0	0,8	-1,0	-3,0	-6,1	-5,1	-0,9	0,8	0,9	3,6

3.2.2 Fogón of Sr. Crescencio Meliñir

Sr. Crescencio Meliñir (Figs.22-23) is 68 years old. He was born and lived in a *ruka* until the 1990s when subsidies were provided for rural social housing by the government following the return of democracy to Chile. The current small *ruka* or *fogón* (hearth) was built three years ago by his son Alex Meliñir who has been influential in the development of eco/ethno tourism in the community. The new *fogón* which is approximately 4m square reused many timbers from a pre-existing barn. Currently Don Crescencio and his wife use the *fogón* for cooking and spend most of the evenings there by the fireside drinking mate. According to Don Crescencio traditional Pehuenche *rukas* and *fogones* were often lined with *quila,* a local bamboo, to provide additional insulation, although this increased the risk of house fires. When well-constructed, the *rukas* maintained the heat well. The current *fogón* is built with more ventilation principally for summer use. Don Crescencio claims that the smoke was never a problem, although recently an eye injury has been irritated by the smoke.

Figure 22: Author and Sr. Crescencio Meliñir outside his *fogón*. Figure 23: Don Crescencio inside *fogón*.

3.2.2.1 Specific in situ measurements: Fogón of Don Crescencio

Table 6: Specific in situ measurements Fogón de Don Crescencio, 24 July 2013

Date 2013	Hour	Location	Dry-bulb temperature (°C)	Black Globe Temperature (°C)	Radiant surface temperature (°C)						Relative humidity (%)	CO_2 (ppm)	Ultra fine particulate material (particles/cm^3)
					North	East	South	West	Ceiling	Floor			
24/07	12:00	Exterior	6,4	-	-	-	-	-	-	-	35,4	406	1654
		Fogón (f)	10,2	23,8	14,0	10,8	10,4	28,6	20,0	3,2	41,2	442	360,000

(f)- Fire lit

With the open hearth lit the indoor dry-bulb temperature is 4°C higher than the external temperature (Table 6) but is not in the comfort zone, unlike the black globe temperature which is. The radiant surface temperatures are close to the dry-bulb temperature except for the west wall which is close to the open fire and the ceiling. Concentration of ultra-fine particulate matter is high.

0,1%	0,1%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,1%
0,1%	0,1%	0,1%	0,1%	0,1%	0,1%	0,1%	0,1%	0,2%	0,2%	0,3%
0,1%	0,1%	0,1%	0,1%	0,1%	0,1%	0,2%	0,2%	0,3%	0,4%	0,4%
0,1%	0,1%	0,1%	0,1%	0,1%	0,1%	0,2%	0,4%	0,6%	0,9%	1,1%
0,1%	0,2%	0,2%	0,2%	0,1%	0,2%	0,2%	0,6%	1,0%	1,4%	1,8%
0,1%	0,3%	0,6%	0,4%	0,2%	0,2%	0,3%	0,6%	1,0%	1,1%	1,2%
0,0%	0,5%	0,9%	0,6%	0,3%	0,3%	0,3%	0,7%	1,0%	0,7%	0,5%

Figure 24: Distribution of daylight factor within the fogón of Don Crescencio 25 July 2014

The natural daylight (Fig.24) is principally concentrated around the doorway which in the case of this *fogón* does not correspond with the area of principal occupation around the open hearth.

3.2.2.2 Continual Measurements: *Fogón* of Don Crescencio

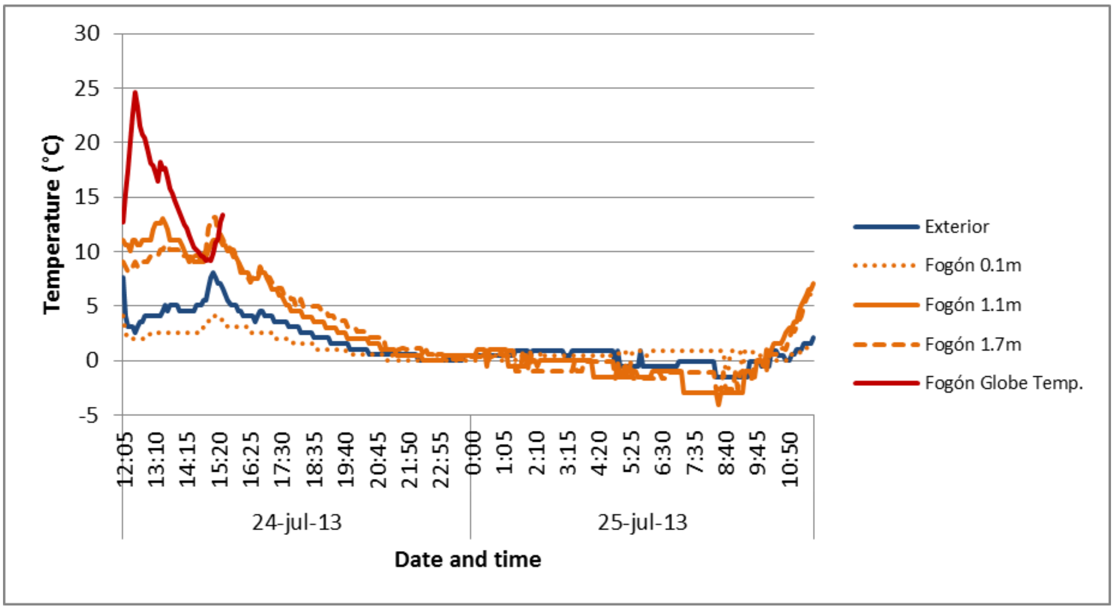


Figure 25: Simultaneous measurments of dry-bulb temperature and globe temperature at different heights. *Fogón* of Don Crescencio 24th-25st July 2013 (Winter)

As with the *rukas* Lafkenche the measurements (Fig.25) show a comfortable globe temperature whilst the hearth is lit, however the dry-bulb temperatures are low and the temperature at 0.1m above floor level is lower than external temperature during the day due to the influence of the high thermal mass of the earthen floor. This thermal mass has a positive influence in the early morning when the temperature at 0.1m remains above 0°C; however the influence is limited and the temperature at 1.1m drops to -4°C, even lower than the external temperature.

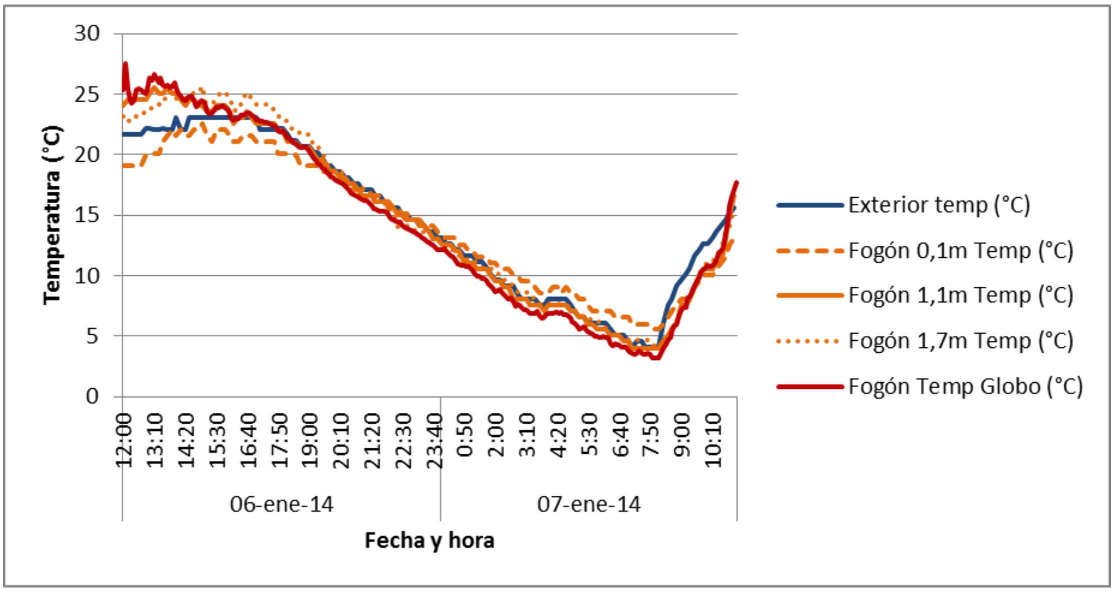


Figure 26: Simultaneous measurments of dry-bulb temperature and globe temperature at different heights. Fogón of Don Crescencio 6th-7st January 2014 (Austral Summer)

The influence of the thermal mass of the earthen floor can also be seen in the summer measurements (Fig.26) where the dry-bulb temperature at 0.1m above floor level is lower during the day and higher during the early morning before dawn. Unlike the winter temperatures, the globe temperature is comparable with the dry-bulb temperature even when the open hearth is lit.

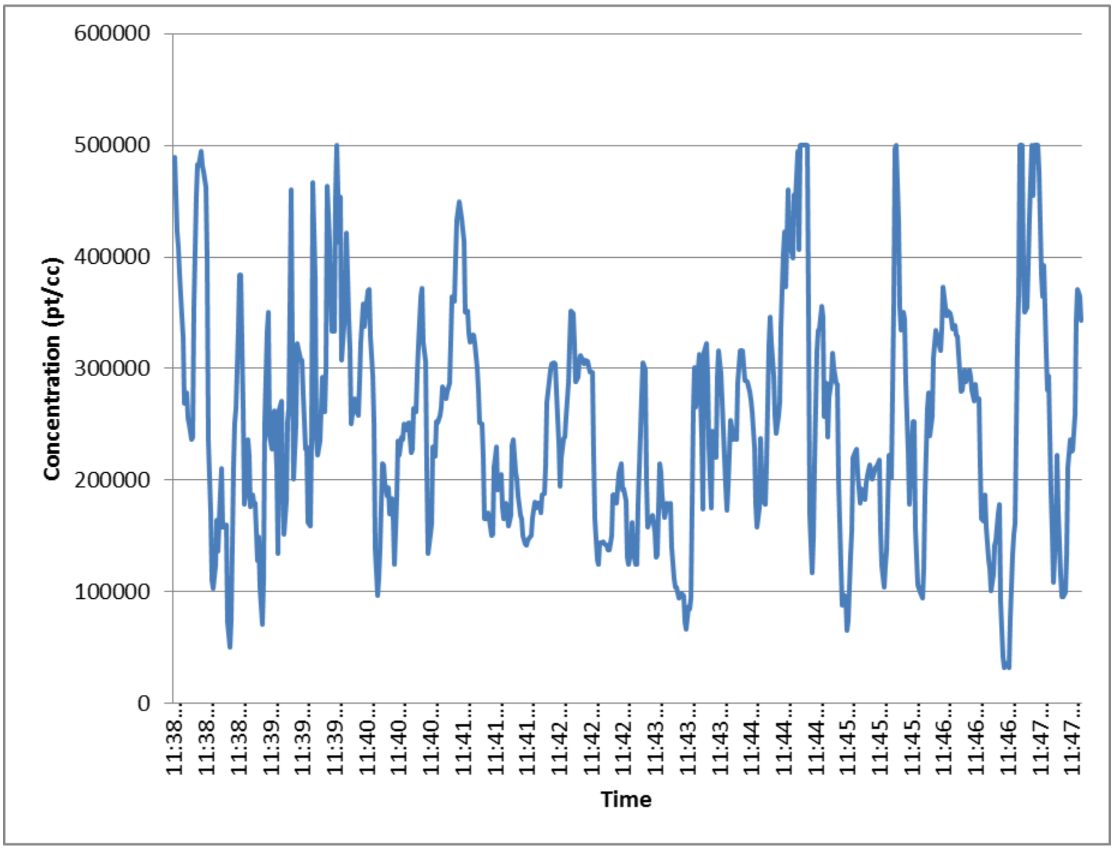


Figure 27: Measurements of concentration of ultra fine particulate matter in the *fogón* of Don Crescencio 25th July 2013 (Austral Winter) with open hearth lit.

As with the Lafkenche *rukas* the concentrations of ultrafine particulate matter is high (fig.27), in some cases exceeding the limit of the measurment instrument (500.000pt/cc.).

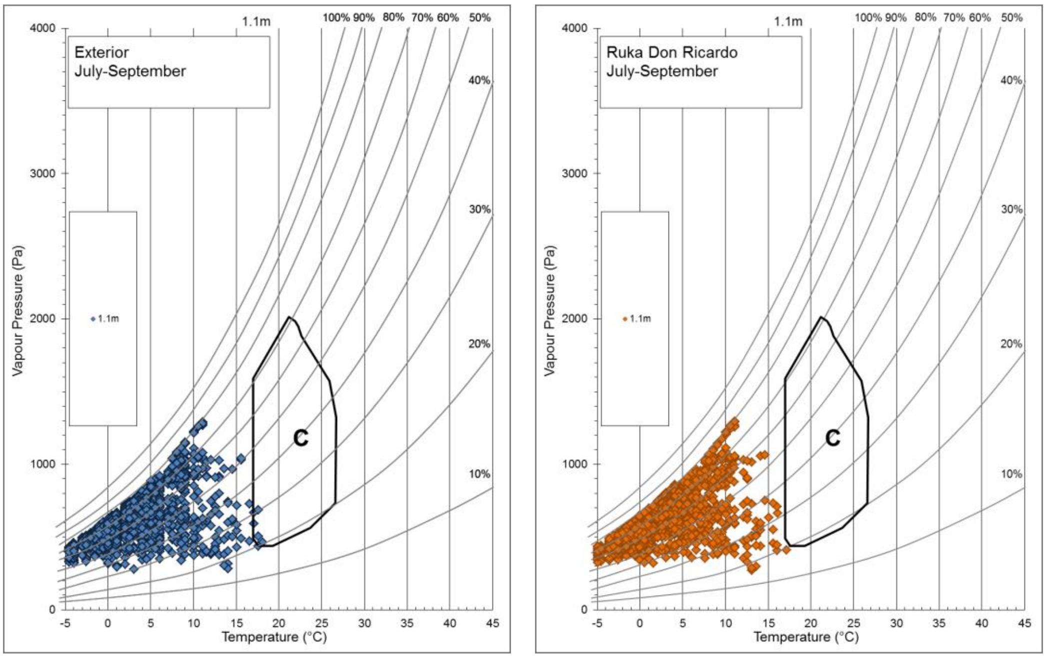


Figure 28 & Figure 29: Psychrometric charts showing temperature and relative humidity of the air externally and in the *fogón* of Don Crescencio from July - September 2013

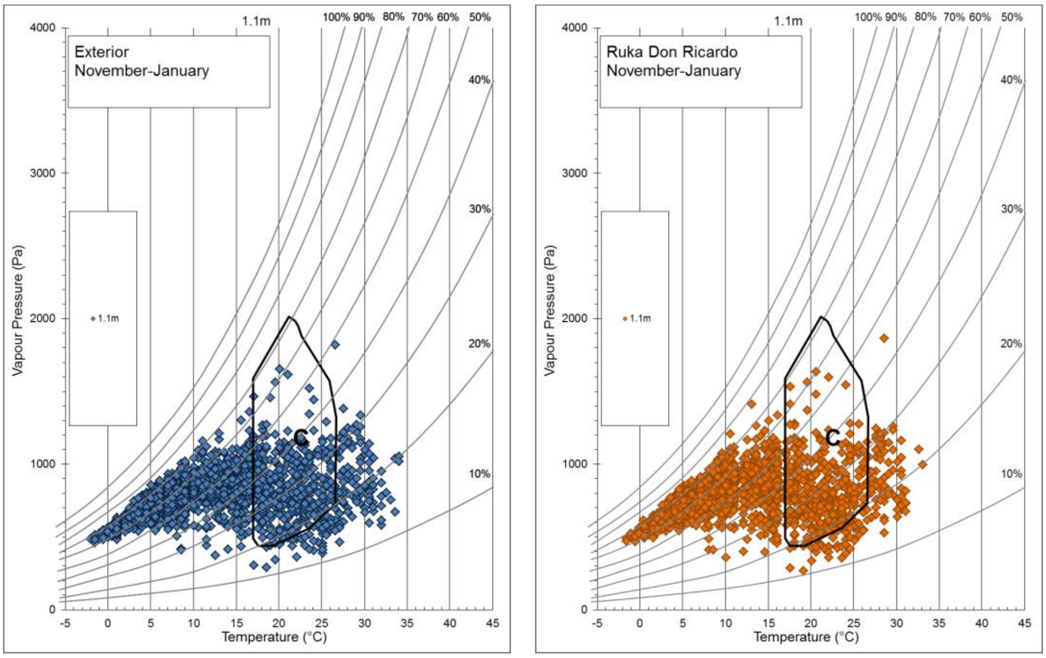


Figure 30 & Figure 31: Psychrometric charts showing temperature and Relative humidity of the air externally and in the *fogón* of Don Crescencio from November 2013 - January 2014

During winter month the results show (Figs. 28&29) that the *fogón* rarely achieves hygrothermic comfort (Givoni 1998) neither does the *fogón* provide the protection against the lowest temperatures provided by the Lafkenche *rukas*. It should however be noted that the external temperatures are more extreme than those of the coast dropping to -7.5°C. The interior temperatures are however more favourable than external conditions with twice as much of the time registering temperatures greater than 10°C. During autumn and early summer (Figs. 30&31) 25% of the measurements both external and internal fall within the higrothermal comfort zone. There is the occasional occurrence of overheating in the *fogón* with 4% of measurements marking more than 27°C; only 2% of external measurements exceed this temperature.

Results: *Ruka* of Sr. Ricardo Meliñir

Don Ricardo is around 60 years old. The *ruka* that he owns (Figs. 32&33) was constructed 7 or 8 years ago to receive visitors. The construction used no power tools using only axes and *corvinas*, two handled saws. The main roof beams are made from fallen araucaria (*Araucaria araucana*) whilst the cladding is of lenga beech (*Nothofagus pumilio*). Don Ricardo confirmed that with a lot of firewood burning it is cosy, although currently they only use the *ruka* when groups of visitors come to Quinquén. The *ruka* is approximately three times the size of the *fogón* of Don Crescencio and unlike the *fogón* has two windows with timber shutters to close them.

Specific in situ measurements in winter showed internal temperatures fractionally below external conditions.

Figure 32: Author and Sr. Ricardo Meliñir outside the *ruka*. Figure 33: Detail of window and roof.

4 Conclusion

The study of the architecture and construction techniques of the Lafkenche and Pehuenche peoples clearly demonstrates differences due to the materials locally available and adaptation to climatic conditions, however both share elements and concepts united by the world outlook of the Mapuche. For example, both have the same orientation with their main entrance facing east, towards the sunrise, to receive the first energy of the day. Both have the open fire as the focal point of daily life and social contact. Also although they use different materials, in both cases they are natural, local and biodegradable, returning in time to the earth. This ephemeral aspect of Mapuche architecture can be considered highly sustainable and low carbon.

The results of the in situ specific and continual measurements show that, when lit, the open hearths achieve a comfortable globe temperature for those close to the fire; however they have little effect on the dry-bulb temperature. It is therefore necessary for the inhabitants to draw close to the hearth to appreciate its warmth. This necessity is prized by the inhabitants, seen as a positive aspect that unites the family and strengthens the bonds and relationship between them. The natural daylighting in the Lafkenche *ruka* is also focused on the area around the hearth, close to the door, reinforcing the importance of this space for daily activities. The interviews corroborate that shown by the results of the globe temperature measurements, that around the fire thermal comfort is achieved in winter. The interviews indicated that in summer the internal temperatures of the *rukas* are more comfortable than the modern houses; however this perception was not conclusively confirmed by the in situ specific measurements of dry-bulb temperature and superficial radiant temperature but continual summer measurements did identify some overheating of the timber cabin. It is important to note that more than one of the interviewees commented that the modern *rukas* are not as well insulated as those built previously. This obviously has an impact on the measurements.

It is however the concentration of ultra-fine particles arising from the open hearth that poses the greatest challenge of achieving environmental comfort in this indigenous architecture. The open, flueless hearth is an important source of heat and communion, yet its negative impact on air quality is notable.

The lessons we can learn from the architecture Lafkenche and Pehuenche do not lead to a simple affirmation that they are examples of sustainable architecture. Their deficits in environmental comfort signify that a direct application of the traditional technologies is not appropriate for modern habitation. However their use of local, low energy, natural materials is highly commendable and it is this aspect which presents an opportunity which could be developed in the search for a new sustainable architecture appropriate to the Araucania Region.

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