Project shelter, Part 1: Fire resistance and thermal insulation

Proyecto Viviendas de Emergencia, Parte 1: Resistencia al fuego y aislación térmica

Rose Marie Garay (Main and Corresponding Author)
Departamento de Ingeniería de la Madera y Biomateriales, Facultad de Ciencias Forestales y Conservación de la Naturaleza, Universidad de Chile
Postal Code 9206, Santiago (Chile)
rgaray@uchile.cl

Wladimir Figueroa
Departamento de Ingeniería de la Madera y Biomateriales, Facultad de Ciencias Forestales y Conservación de la Naturaleza, Universidad de Chile
Postal Code 9206, Santiago (Chile)
wfigueroasoto@gmail.com

Francis Pfenniger
Departamento de Arquitectura, Facultad de Arquitectura y Urbanismo, Universidad de Chile
Ave. Portugal 84, Santiago, Región Metropolitana (Chile)
fpfenniger@uchilefau.cl

Ricardo Tapia
Instituto de la Vivienda, Facultad de Arquitectura y Urbanismo, Universidad de Chile
Ave. Portugal 84, Santiago, Región Metropolitana (Chile)
rtapia@uchilefau.cl

Jorge Larenas
Instituto de la Vivienda, Facultad de Arquitectura y Urbanismo, Universidad de Chile
Ave. Portugal 84, Santiago, Región Metropolitana (Chile)
jlarenas@uchilefau.cl

Manuscript Code: 855
Date of Acceptance/Reception: 20.07.2017/11.11.2016
DOI: 10.7764/RDLC.16.2.339

Abstract
In Chile there is a gap that needs to be filled in order to have a positive impact upon emergencies, particularly in emergency houses (EH) In this study were evaluated the properties of a prefabricated prototype based on a "Structural Insulated Panel" 64mm thick (SIP64), built by two OSB panels bonded with a two component polyurethane adhesive to a high density expanded polystyrene core. SIP64 was manufactured as a main element for construction of EH. The thermal insulation was evaluated by NCh 853:2007 and was equal to 1.41 [m*K/W] equivalent to a thermal transmittance to 0.71 [W/m*K]. In fire resistance (FR), the quality was determined by NCh 935/1.Of97. The FR was F15 class, minimum safety requirement for bearing vertical elements and non-supportive frame walls. It is feasible to use the SIP64 as the main element in the construction of EH. FONDEF D09I1058 project has developed Technical and Normative standards for wood shelter. As main products Manuals for Manufacturing, Installation, Technical Specifications and Regulations for EH were developed and are available online for free.

Key words: Emergency house, shelter, habitability, settlement, technical and normative standards for emergency houses, SIP panel, thermal insulation, fire resistance.

Resumen
En este estudio se evaluaron las propiedades de un prototipo prefabricado basado en un "Panel Estructural Aislado" de 64 mm de espesor (SIP64), construido por dos paneles OSB unidos con un adhesivo de poliuretano de dos componentes a un núcleo de poliestireno expandido de alta densidad. SIP64 se fabricó como un elemento principal para la construcción de viviendas de emergencia (VE). El aislamiento térmico fue evaluado por NCh 853: 2007 y fue igual a 1,41 [m * K / W] equivalente a una transmitancia térmica de 0,71 [W/m*K]. En resistencia al fuego (RF), la calidad fue determinada por NCh 935 / 1.Of97. La RF fue F15, requisito de seguridad mínimo para los elementos verticales y tabiques no soportantes. Es posible utilizar el SIP64 como el elemento principal en la construcción de VE. El proyecto FONDEF D09I1058 ha desarrollado estándares técnicos y normativos para viviendas de emergencia de madera. Como principales productos fueron desarrollados: Manuales de Fabricación, Instalación, Especificaciones Técnicas y Reglamentos para VE y están disponibles en línea de forma gratuita.

Palabras clave: Vivienda de emergencia, refugios, habitabilidad, asentamiento, normas técnicas y estándares para viviendas de emergencia. panel SIP, aislamiento térmico, resistencia al fuego.

Introduction

Shelter, is a kind of house that actually has no technical regulations to establish minimal comfort criteria as they do not depend from de Ministry of Housing but from Interior Ministry. In fact, Shelter or EH are not regulated by any authority (Ministerio de la Vivivenda, 2017).

There are many examples of shelter in the world, even patented, but none is regulated by governments. Even more, there are no regulations that establish basic conditions for transient habitability under minimum technical criteria nowhere in the world (Cardona, 2008; Secretaría General de la Comunidad Andina, 2017; Sehnbruch, 2017).

A 18sq.mt precarious house consisting of eight prefabricated unpainted wood panels of wet radiata pine, corrugated steel cover plates, two windows, one door and other complementary elements, known as “mediagua” is used without standard in Chile as an emergency housing. Back in 1966, "Fundación Vivienda" was created to provide temporary housing solutions to families in extreme poverty as those who have suffered a natural disaster, through direct or indirect actions(Garay, Pfennieger, Tapia, & Larenas, 2014; Ministerio de Vivienda y Urbanismo, 2016).

For nearly 46 years, there has been an implicit acceptance by the State of Chile to deliver this type of prefabricated homes, a temporary solution, which is supported in the absence of regulations, prioritizing quantity and fabricating and building speed over quality of the product, leaving behind concepts as basic and important to the healthy development of Chilean families as the housing wellness itself.

This housing wellness can be evaluated by various factors of habitability and safety. The idea of habitability responds to compliance with certain parameters and standards among which stand out: interior lighting and sunlight, overcrowding, heat and sound insulation (APA – The Engineered Wood Association, 2014; González, Vásquez, & Hernández, 2016; Ministerio de Vivienda y Urbanismo, 2016). Security, meanwhile, should contribute to exemption from danger, harm or risk, so are considered security parameters in electrical and sanitary installations, structural safety, fire safety and security against accidents (Bustamante & Rozas, 2009; Flores, 2015; Garay, 2015). “The wide range of buildings in Chile has a reduced capacity to limit the energy demand for thermal conditioning. This phenomenon is greatly attributed to the low thermal insulation standards contemplated in the current regulations and the lack of guidelines focused on limiting air infiltration” (Bobadilla, Diaz, Figueroa, & Arriagada, 2014), in social housing this has been approved and regulated by the OGUC, but even lower conditions can be expected in unregulated emergency housing.

In recent years, Latin American countries have suffered from the constant housing deficit, which destroys the possibilities of the first property by the neediest populations. Therefore, it is necessary to propagate studies, research and information on industrialized housing construction techniques, such as wood frame (Almeida et al., 2016).

The research project Integrated Design for the Reconstruction of Energy Efficient Dwellings (Escorcia et al., 2013) expose a strategy of diagnosis and evaluation to the thermal improvement through outer envelops for low cost housing located in reconstruction areas. It develops an analysis and solution for the thermal envelop that can be applied in the earthquake’s most affected regions in the central-south areas of Chile (Maule, Biobío and Araucanía). It presents a case study with quantitative methods for the technical and financial validation of a proposal for thermal improvement, and qualitative methods for the social validation of the involved actors. The results confirm a strategy that may contribute in the reduction of the consumption and developing attitudes able to direct towards the promotion of energy efficiency. The outcomes may be generalized and the experiences can apply to other regions, looking after their particular conditions (Castro, Sarmiento, Edwards, Hoberman, & Wyndham, 2017).

In this study the properties of a prefabricated panel prototype is evaluated based on Structural Insulated Panel (SIP) construction technology characterizing it as a basic element for emergency housing. The housing welfare is the perception and valuation ascribed to the total of the components of a residence, according to psychosocial, cultural, economic variables and political order (Corporación de Desarrollo Tecnológico, 2015; Ministerio de Vivienda y Urbanismo, 2016).

This housing welfare can be assessed by various factors of habitability; physical-spatial, psychosocial, thermal, noise and light, and also for safety factors; such as structural, fire resistance, accidents, durability and maintenance(Mahuzier, 2017; Pérez, 2016).

It was necessary to define the factors of habitability and safety to be considered as a minimum for emergency housing: Thermal insulation, fire resistance and protection of structural components that are exposed to weathering are reported in this document.(Garay et al., 2014; Ministerio de la Vivienda, 2017; Wagner, 2017)

Materials and methods

As a result, the project addressed this issue with different private and public agencies (MINVU; ONEMI, FOSIS) to find a consensus regarding the minimal technical criteria this emergency house (EH) should match in the different country climatic zones and also how they should be installed on site after the occurrence of natural disasters that affect the population. These regulations are also applicable in case of emergency houses in social vulnerability. Based on this arrangements the project designed, fabricated, installed and evaluated prototypes in 5 different climatic zones of the country and after that provided technical guarantees of the quality of the EH that were tested. This may serve as a model for other manufacturers in the private sphere as long as they respect the technical standards, which are particularly well resolved in timber construction due to Chilean experience and skills.

In this study were evaluated the properties of a prefabricated housing prototype with 64mm thick panel based construction technology known as "Structural Insulated Panel" (SIP) (hereinafter SIP64), which was built by two 9.5 mm OSB bonded with a two-component type polyurethane adhesive to a high density expanded polystyrene core.

This panel was manufactured in accordance with NCh 3393:2016 (Instituto Nacional de Normalización, 2016) as a main wall element in the construction of emergency housing, housing solutions to be transient which at this time have no regulations stipulating minimum habitability standards and safety requirements as the ones that exist for permanent housing. It was our interest to evaluate the thermal insulation and fire resistance of the SIP64 panel. The NCh853: 2007 thermal insulation standard was used to calculate the thermal resistance and thermal transmittance of the panel and then stated what climatic zones of the country meets the thermal requirements dictated by the General Urbanism and Construction (OGUC) (Instituto Nacional de Normalización, 2007; Ministerio de la Vivienda, 2017) for perimeter walls. The Table 1 shows the requirements for dwellings. The thermal zoning of Chile is based on the heating degree-days (HDD) concept, in a specified period of time (winter), is obtained as the summation of the differences between a base temperature (15°C) and the day-averaged temperatures minus the base temperature. The heat to overcome the difference between the base temperature and the comfort temperature is supplied by the internal heat gains such as occupants, appliances, and lighting. The act has established the conductive thermal transmittance (U) of the envelope of dwellings 70 for each thermal zone of Chile.

Table 1. Thermal transmittance (U) for Chilean thermal zone according to heating degree-days (HDD).

		U/W(m^2k)			
Thermal Zone	Heating degre-days	Walls	Roof	Vent. Roof	Cities Localities
1	≤ 500	4.0	0.84	3.60	Antofagasta
2	>500 - ≤ 750	3.0	0.60	0.86	Viña del Mar
3	>750 - ≤ 1000	1.9	0.47	0.70	Santiago (Puente Alto)
4	>1000 - ≤1250	1.7	0.38	0.60	Concepción
5	>1250 - ≤ 1500	1.6	0.33	0.50	Temuco
6	>1500 - ≤ 2000	1.1	0.28	0.39	Puerto Montt
7	≥ 2000	0.6	0.25	0.32	Punta Arenas

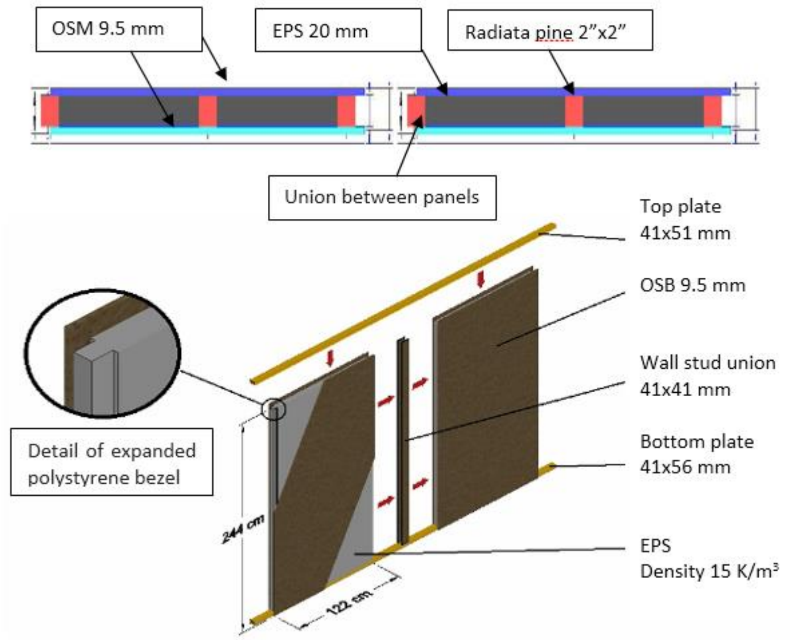
In terms of fire resistance, the quality of SIP64 panel was determined empirically to withstand a common fire under test under standard NCh 935/1:1997 (Instituto Nacional de Normalización, 1997) and settled in what parameters satisfies the minimum fire safety tax by OGUC to vertical elements. The fire resistance of the panel corresponds to the F15 class, which meets the minimum safety requirements for supportive and non- supportive vertical elements (walls).

SIP64 1.22 x 2.44 m panels whose basic structure is composed of:

- Core: high density expanded polystyrene (15 kg/m^3) and 45 mm thick.
- Faces: Standard structural OSB is used in format 1.22 x 2.44 x 9.5 mm.
- Adhesive: based on two-component polyurethane.

In the upper and lower ends of the panel, polystyrene is trimmed to place sills, necessary joints for the construction system. Likewise, in the side faces the polystyrene core carries two recesses along the entire length of the panel, allowing the insertion of the uprights to the junction between side panels (Figure 1).

Figure 1. Configuring the walls construction system.



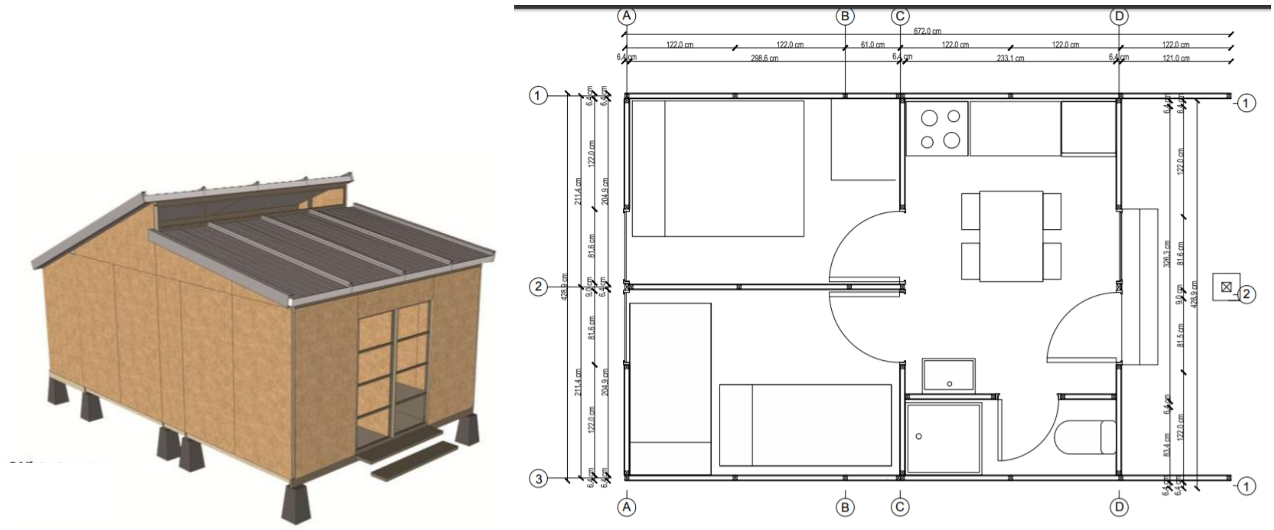
The Table 2, shows thermal resistance of materials.

Table 2. Thermal resistance of expanded polystyrene and OSB.

Materials	Density (Kg/m)	Thickness (mm)	Thermal conductivity (W/m*K)	R (m*K/W)
Expanded Polystyrene (EPS)	15	45	0.0413	1.09
Oriented Strand Board (OSB)*	700	9.5	0.13	0.07

Figure 2, presents three-dimensional and plan view the housing prototype.

Figure 2. Plant and three-dimensional view.



The exterior finishing protection systems have been upgraded according to the climatic conditions in each zone. In the north and center of country, the walls were protected with two hands of water-borne topcoat, plus the application of elastomeric stucco. In contrast, in the south, the walls are coated with aluzinc sheets and finished with a specially formulated acrylic paint for aluzinc. This applies in this case for roof and walls.

Minor modifications were made to the designs: superior ventilation openings (Figure 3), are higher and can be opened in the north and central area, however in the south they are lower and remain closed, allowing the passage of light. Also in the north the rear access doors are higher, reach the floor (Figure 4), allowing better ventilation. In southern and colder areas they are only half of the wall, collaborating with improved thermal insulation.

Likewise in the south, the front terrace has been protected from rain, while in the north it remains completely open.

Figure 3. Superior ventilation open and closed according to climatic zone.

Figure 4. Outside protection sequence.

Thermal insulation

The Chilean Statement NCh 853:2007 (Instituto Nacional de Normalización, 2007) was utilized, this norm settles the calculation procedures to determine resistance and thermic transmittances for construction elements, particularly those of the thermal envelope, and in general, any other element that separates different temperature environments. The calculation procedures set in this Statement are based on the assumption that the heat flux is developed in accordance with the Law of Fourier, at stationary state.

The method was to determine the thermal resistance of a layer of material of plane and parallel surfaces, by the following equation:

$$\boxed{R = \frac{e}{\lambda}} \qquad (1)$$

Where:
R : Thermal resistance of the layer of homogeneous material [m^{2}K/W]
e : Thickness of the layer of homogeneous material [m]
λ : Thermal conductivity of the material [W/m^{2}K]
With this information, the total thermal resistance (R_T) of the element was calculated as a compound of the sum of the thermal resistances of the different material layers that form the construction system ($\sum R_i$), adding the thermal resistances of both the inner surface (R_{si}) and the outer (R_{se}), which are tabulated in this Statement, according to the direction of heat flow, the position and location of the spacer element and the wind speed (equation (2).

$$\boxed{R_T = R_{si} + \sum R_i + R_{se} \qquad [m^2 * K / W]} \qquad (2)$$

Once the total thermal resistance (R_T) was obtained the thermal transmittance (U) of the SIP64 panel was determined as follows:

$$\boxed{U = \frac{1}{R_T} \qquad [W / m^2 * K]} \qquad (3)$$

Finally with these values of thermal transmittance (U) and total thermal resistance (R_T the thickness of the SIP panel was calculated in order~~,~~ to meet the thermal requirements for the enclosure walls in Chile's different climatic zones either because the thermal transmittance (U) is less or equal, or the total thermal resistance (R_T) is equal or superior to what is dictated by OGUC for the determined areas.

Fire resistance

The fire resistance test was carried out on the dependencies of the Institute of Materials Research and Testing (IDIEM), University of Chile, by applying Chilean Standard Of NCh 935/1. 97.

The method consisted of exposing the SIP64 panel under test, with one side heated by a furnace, to impart a temperature curve according to the standard time-temperature specified in NCh Of 935/1. 97, governed by the relationship (4):

$$\boxed{T - T_0 = 345 \log (8t + 1)} \qquad (4)$$

Where:
t: Time in minutes considered from the start of the trial
T: Furnace temperature at time t, measured in ºC
T_0: Initial furnace temperature, measured in ºC

According to this statement, the tested element must be analyzed under normal operating conditions, in order to reproduce, during the test, a similar system of embedding, supports and loads to which it has to be subjected. To accomplish this, the tested element has to be of real size. The sample dimensions have to fit the furnace, so a 2.2 m wide by 2.4 m high panel was fabricated. This implies that two SIP64 sample panels, of 1.1 x 2.4 m were used, assembled by an upright edge and fastened peripherally by an upper and a lower hearth. In addition, throughout the entire assay, the magnitude of the compressive load (120 kg/m) had to be kept constant.

The furnace employs a LPG burner with 500,000 kcal/h power and has an opening capable of supporting the element under test. The temperature was measured by thermocouple on the side exposed to fire and infrared radiation in the unexposed side.

According to the Chilean Statement NCh 935/1 of. 97, the trial is due to continue until the failure of any of the following requirements of the test is observed:

a) Load Bearing Capacity: Determined by the instant in which the element can no longer continue to carry the load bearing function for which it was designed.
b) Thermal isolation: Determined by the time spent for the temperature of the unexposed side to rise to 195°C (point) or 140°C (average) over the initial environmental temperature.
c) Water tightness resistance: Determined by the instant in which the flames (or high temperature gases) are filtered by the joints or through any cracks or fissures formed during the test.
d) Flammable gases emission: Gases emitted from the unexposed side, are considered flammable if, by approximation of a flame, they burn and spontaneously continue burning for at least 20 seconds after removing the flame.

It has to be pointed out that at baseline, ambient temperature was 15°C; the relative humidity was 54%; and the furnace recorded an initial temperature of 24°C.

Results and discussion

Thermal insulation

Chile has incorporated changes described in Section 4.1.10 of the OGUC: "first and second stage" of thermal regulation. These requirements have set thermal conditioning to the envelope of residential buildings. With no requirements in the past, these requirements were first set for roofing complex (2,000) and later for walls, ventilated floors and maximum window areas (2,007). In effect, since 2,007 (Ministerio de la Vivivenda, 2017), this amendment provides that the envelopes shall have a thermal transmittance "U " equal to or less, or a total thermal resistance " Rt " equal to or superior to the set for the area in question according to Table 3.

Table 3. Thermal insulation requirement for each envelope in climatic zones.

Climatic	Ceiling		Wall		Floor	
Zone	U(W/m^{2}K)	Rt (m^{2}K/W)	U (W/m^{2}K)	Rt (m^{2}K/W)	U (W/m^{2}K)	Rt (m^{2}K/W)
1 Large North and Coast Region IV	0.84	1.19	4	0.25	3.6	0.28
2 Desert and part IV and V Regions	0.6	1.67	3	0.33	0.87	1.15
3 II, IV, VI and RM Regions	0.47	2.13	1.9	0.53	0.7	1.43
4 VII y VIII Regions	0.38	2.63	1.7	0.59	0.6	1.67
5 Range and IX Region	0.33	3.03	1.6	0.63	0.5	2
6 Interior: IX y X Regions	0.28	3.57	1.1	0.91	0.39	2.56
7 Range and austral zone	0.25	4	0.6	1.67	0.32	3.13

Source: (Corporación de Desarrollo Tecnológico, 2015; Ministerio de la Vivivenda, 2017).

The total thermal resistance (Rt) and thermal transmittance of SIP64 was calculated (Table 4) and in the table 5, it presents the compliance thermal regulation for SIP64.

Table 4. Total thermal resistance and total thermal transmittance of SIP64 (m*K/W).

R EPS	R OSB (x2)	Rsi	Rse	Rt	Up
1.09	0.146	0.12	0.05	1.41	0.71

EPS: Polystyrene expanded; OSB: Oriented strand board; R_T: total thermal resistance.
R_{si}: inner surface () and R_{se}:outer surface.

Table 5. Compliance thermal regulations Rt SIP64 as thermal zone of the country.

Zone	Requirement Rt	SIP64 Rt	Conclusion
Zone 1	0.25	1.41	MEETS
Zone 2	0.33	1.41	MEETS
Zone 3	0.53	1.41	MEETS
Zone 4	0.59	1.41	MEETS
Zone 5	0.63	1.41	MEETS
Zone 6	0.91	1.41	MEETS
Zone 7	1.67	1.41	FAILS

Analytical calculation obtained from the thermal resistance of the SIP64 panel was equal to 1.41 [m*K/W] equivalent to a thermal transmittance of 0.71 [W/m*K] therefore states that the SIP64 meets the thermal requirements dictated by the OGUC for perimeter walls in all climatic zones except zone VII.

In Chile, the panel SIP75 reaches an Rt of 1,752 [m*K/W] for Tecnopanel (Tecnopanel, 2008), fulfilling the thermal requirement for perimeter envelope walls in all thermal areas. And Ingepanel (INGEPANEL, 2011) has a thermal resistance value of 1.96 [m*K/W] for the 86mm thick SIP panel, made with two 9.5 mm thick OSB attached to a polystyrene foam core of 67 mm thick and empirically obtained under standard test.

When calculating the thermal resistance under Chilean NCh 853.Of 91, thermal resistance was equal to 1.93 [m*K/W], close to the value determined in practice by a good predictive method for determining the thermal insulation of SIP panels.

Roof insulation thickness was varied to comply with the thermal resistances of each area.

According to (APA – The Engineered Wood Association, 2014), the "framing factor" is used to express a percentage of the total solid exterior wall area occupied by framing members, including headers. The wood wall U-factor in the IECC is calculated based on the assumption that the area of a standard residential wall (solid portions, excluding fenestration) consists of 25 percent framing and 75 percent insulation. This percentage of framing includes headers, which are typically 4 percent of the wall area, plus studs, plates and full-cavity width blocking. Framing that does not bridge the insulation (e.g., exterior or interior strapping, let-in bracing, rim joist) is excluded.

Fire resistance

Title 4 from chapter 3 of the OGUC, states that all buildings must meet minimum standards of fire safety, in order to facilitate rescue of occupants, minimize the risk of fire, prevent the spread of and facilitate fire-extinguishing fires. To that end, in OGUC buildings are classified in types a, b, c, and d according to:

- The building use (e.g., residential, office, warehouse, industrial)
- The floor area
- The number of floors
- The maximum number of occupants
- Fuel load density (mean and maximum points).

Based on this classification, fire resistance requirements, expressed as an index of classification for each of the building types are set, so as required fire walls, partition walls between units, stairs and horizontal supporting elements, among others, meet certain degree of fire resistance.

It is also worth noting that in OGUC's article 4.3.5 numeral 14, is issued that: the isolated, paired or continuous housing up to 2 floors, not exceeding 140 m^2 built area, have to resist at least F15 fires in its entirety and supportive components, provided that the abutment wall or partition wall, as applicable, comply with the requirements of partition walls between units This means that it could propose a detached two-story building in which the dividing wall meets the required class F60, and all other structural elements can be classified as F15.

Regarding the test results for fire resistance SIP64 obtained on the basis of the technical report issued by the Fire Laboratory of IDIEM, the following is mentioned:

- Load bearing capacity: The element is subjected to a mechanical load of 120 Kg /m linear. During the test the panel suffered deformations, which did not caused failure.
- Thermal insulation: The maximum permissible temperature spot of 195 ºC on the side facing the fire occurred at 17 min into the test, time at which the average temperature recorded 134 ºC.
- Sealing: The element kept flame tight to the end of the test.
- Emission of flammable gases: No flammable gases were emitted during the test.

Consequently the fire resistance of SIP64 panel found to be 17 minutes, reaching the F15 classification according to Table 6.

Table 6. Classifying the fire resistance of a building element.

Type	Duration (minutes)	
F0	≥ 0	< 15
F15	≥ 15	< 30
F30	≥ 30	< 60
F60	≥ 60	< 90
F90	≥ 90	< 120
F120	≥ 120	< 150
F150	≥ 150	< 180
F180	≥ 180	< 240
F240	≥ 240	

Source: Ministerio de Vivienda y Urbanismo (2014).

In Chile, the only valid method for determining the fire resistance of building elements is an empirical test in specialized laboratories, by applying the NCh 935/1 of. 97. An alternative that allows to propose an analytical justification of the fire behaviour of light wood paneling is the Component Additive Method (CAM), The National Building Code of Canada provides architects, engineers and builders with a simple, practical calculation method for assigning fire-resistance ratings to wood-frame and steel-frame wall, floor and roof-ceiling assemblies. It was originally devised in the early 1960s and is commonly known as the Component Additive Method (CAM), (American Wood Council, 2014), bases in Rules of Harmathy (Table 10). A collaborative industry–government research program was carried out recently at the National Research Council Canada to develop new fire-resistance ratings for gypsum-board protected walls. Forintek Canada Corp. and the Canadian Wood Council participated in that program on behalf of Canada's wood industry. As part of the research program, a number of full-size fire-endurance tests were carried out on wood-frame and steel-frame walls. The results of those fire tests have allowed us to revisit those sections of the Component Additive Method which are applicable to light-frame walls lined with gypsum board. This detailed review of reports of standardized elements of partitions, roofing structures and beams and hardwood floors trials, allowing substantiate time values assigned to the contribution to the fire resistance of each individual component as a constructive element ((American Wood Council, 2014; Wagner, 2017). The times assigned to different components are as shown in Tables 7, 8 and 9.

Table 7. Trim Allotted time.

Plywood with PF bounded Description	Thickness (mm)	Allotted time (min)
Phenolic plywood Douglas fir	9.5	5
Phenolic plywood Douglas fir	12.5	10
Phenolic plywood Douglas fir	16	15
Plasterboard	9.5	10
Plasterboard	12.5	15
Plasterboard	16	20
Double plasterboard	9.5 + 9.5	25
Double plasterboard	12.5 + 9.5	35
Double plasterboard	12.5 + 12.5	40

Table 8. Time allocated to components timbered.

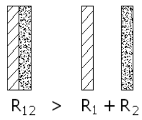
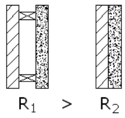
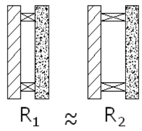
Description wooden structure	Spacing (cm)	Allotted time (min)
Wooden studs	41	20
Wooden beams	41	10
Lattice floor and roof trusses	61	5

Table 9. Allotted mineral wool insulation inside.

Description	Weigth (Kg/m^2)	Alloted time (min)
Mineral wool	> 1.25	15

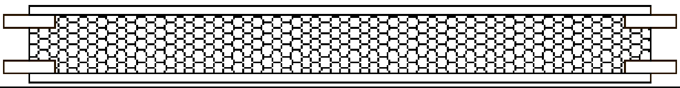
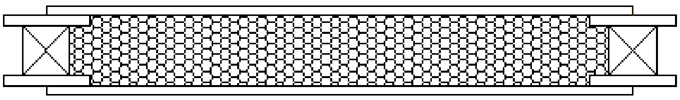
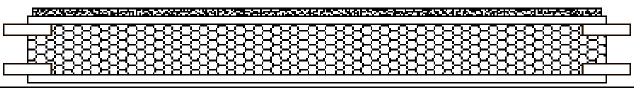
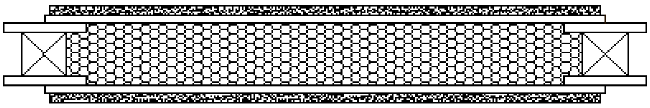
Mineral wool	< 1.25	5

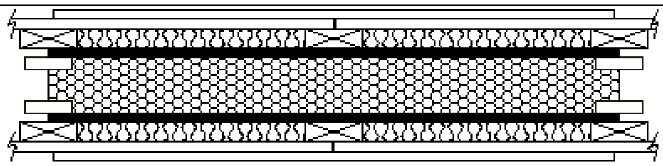
Table 10. Rules of Harmathy.

Description	scheme	Criterion
Rule 1. The fire resistance of an element composed of several layers is greater than the partial sum of the resistances of each individual layer.		$R_{12} > R_1 + R_2$
Rule 3. The fire resistance of an element composed of several chambers separated by air layers is greater than the resistance of an element of equal weight but without inner tubes.		$R_2 > R_1$
Rule 5. The fire resistance of an element does not increase as a result of increasing the thickness of an air chamber.		$R_1 \approx R_2$

Moreover, in the Official list of fire behavior of elements and building components a solution for perimeter walls and / or partitions, structured with SIP building system, which meets the minimum requirement for party walls, is shown (F60). This and other solutions of interest are detailed in Table 11, mentioning both the total thickness of the construction element (E_T) as their relative rankings of fire resistant (RF) (Ministerio de Vivienda y Urbanismo, 2014).

Table 11. Fire behaviour, constructive solutions for the complex of walls.

Solution	Description	E_T (mm)	FR
1. wall edge y/o dividing	SIP Panel OSB consists of two 9.5 mm thick, glued to a core of polystyrene foam density 15 kg / m^3 and 56 mm thick. The panels are assembled together singing and are linked with two tabs OSB 50 x 11.1 mm inserted into the recesses of polystyrene plates bolted to OSB. 	75	F15
2.- Dividing wall	SIP panel consisting of two plates OSB "Smart Side" of 11.1 mm thick glued to a core of expanded polystyrene 67.2 mm thick whose density is from 15 kg / m^3. The connection between panels is implemented with an H- profile composed of a core of Radiata Pine 45 x 45 mm brushed and wings OSB plywood 90 x 11.1 mm screwed and glued the ribbon. 	90	F15
3.- wall edge y/o dividing	SIP standard panel of 75 mm coated on one side (inside) with a sheet of plasterboard "Std" 10 mm thick, bolted to the structure. 	85	F30
4.- Dividing wall	SIP panel thickness 90 mm, covered on both sides with a sheet of plasterboard "Std" thick 10 mm. 	110	F30
5.- Dividing wall	SIP panel 75 mm thick on both sides of screwed studs Radiata Pine 30 x 90 mm, spaced every 0.6 m. As termination takes overlapping two sheets of plasterboard "Std" thick 10 mm. The gaps are filled with glass wool 50 mm thick (compressed to 30 mm) with a nominal density of 14 kg/m^3	175	F60



The trial results and analysis of the above table shows that both SIP64 like SIP75 and SIP90 are classified as F15, therefore it can be inferred that an increase in the thickness of the expanded polystyrene does not provide enhanced fire resistance and their behaviour resembles the nule fire resistance effect of an increasing air chamber as the 5th Harmathy's rule states (*"the fire resistance of an element cannot be increased as a result of increasing the thickness of an air chamber"*). Consequently, the fire resistance of these panels is determined almost exclusively by the coatings. Usually an OSB board 9.5 or 11.1 mm thick can last between 7-9 minutes in front of the fire meanwhile the polyurethane is consumed in a minute (Pérez, 2016) after the first OSB board is consumed.

That is further improved by incorporating a 10mm thick standard plaster board on the inner surface (exposed to the fire) of a SIP75 panel, increasing the element's fire resistance from F15 to F30 (solution 3). However it fails to classify as F60 when another layer of the same material (plaster board) on the outer face is added (solution 4). This rate (F60) is achieved by incorporating two sheets of 10mm plasterboard on each side with wooden racks and filled with mineral wool (solution 5). This and other constructive solutions in wooden partition walls, respond to an F60 classification, can be found in MINVU's website.

To meet the rules established by the Ordinance regarding fire safety, someone could build less than 140 m^2 and up to two stories house only with SIP64 panels for all structural and non-structural (e.g., half-floor building elements structure roof, supportive walls), except the dividing wall or partition between units, which require F60 fire resistance. Based on the times assigned by the CAM and the Rules of Harmathy, one could pose a dividing wall solution that meets the F60 requirement as follows:

1) From Table 7 a 9.5 mm thick plasterboard contributes with 10 minutes of fire resistance and 25 minutes if a double plaster board is used, consistent with the 1st Harmathy's rule.
2) Table 10, the F15 SIP75 classifies as F30 if a 10mm thick plaster board is added at the fire exposed side. This means that the contribution of the plasterboard panel is at least 15 minutes, although individually plasterboard 10 mm may be assigned a shorter fire resistance (according to table 7).
3) Because the SIP64 and SIP75 panel classified as F15, a party wall can be designed similar to solution 5 of Table 10, which uses a SIP64 instead of a SIP75 and a double layer of plasterboard (i.e. 2 x 10 mm thick) screwed on each side of the panel. If this is subjected to CAM it should be classified as F60, as shown in Table 12.

Table 22. Dividing wall F60 structured with SIP64.

Description Dividing Wall	Time (minutes)
Double plasterboard (10 mm + 10 mm)	25
SIP 64	15
Double plasterboard (10 mm + 10 mm)	25
RF index dividing wall	65

In Chile there are only two experimental centers, certified by MINVU approved to realize these tests.

Requiring a standardized full-scale fire resistance test, resulting in taxation, inhibits innovation and promotes a bureaucratic hurdle, besides being expensive, requires considerable time (Wagner, 2017).

To validate the CAM, it is imperative to develop a regulation governing the manufacture of materials used in construction, as applied in the US, with the Regulations Product Volunteers (Voluntary Product Standard) because so far is regulated by each company, generating differences in both composition (density and product quality), resulting in different fire resistances.

Finally, Figure 7 shows a summary of technical criteria for habitability Shelter that comprises:

Summaries of technical criteria for Shelter habitability.
Technical criteria:

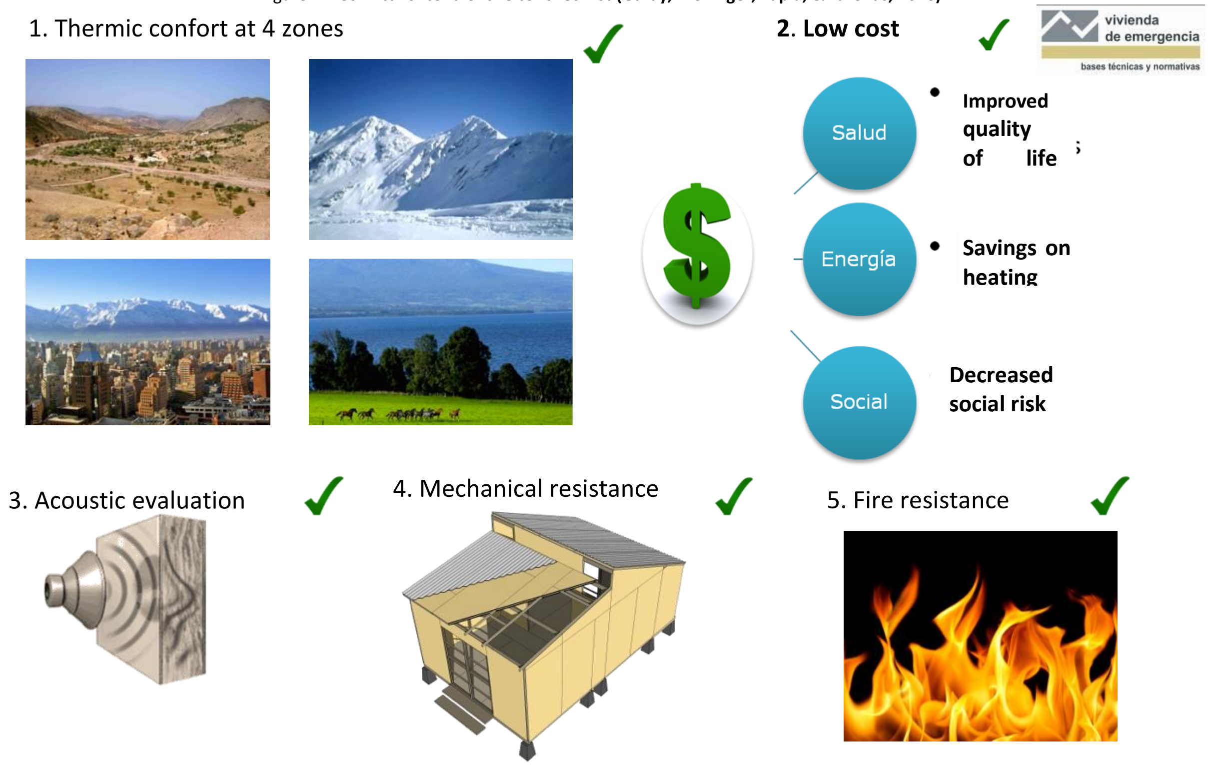
- Air, water and wind tightness
- Fire Resistance
- Conditions of thermal comfort (OGUC)
- Acoustic insulation as a consequence of compliance with the other priority criteria
- Durability of at least 5 years
- Overloading of wind, snow and earthquake as regulations.

Dimensional standards:

- ENCLOSURES: AT LEAST 2.
- SURFACE: MINIMUM OF 24 M2 OR 6 M2 PER CAPITA.
- INTERIOR HEIGHT: 2.2 M.
- HEIGHT 2.0 M BEAMED OR LINTELS.
- INTERNAL VOLUME: 8.0 M3 MINIMUM PER PERSON.

Other Considerations and Recommendations:
To foster and support the internal organization and leadership for interaction with authorities
To conserve, maintain and strengthen social networks
Development of productive public spaces – gardens.

Figure 7. **Technical criteria of shelter checklist (Garay, Pfenniger, Tapia, & Larenas, 2016).**



Conclusions

Technical basis for Emergency Housing and Regulation are available. All the developed information is contained at Manuals of Manufacturing, Installation, Technical specifications and Regulations, all of which are available online on the website of the Faculty of Science Forestry and Nature Conservation from the University of Chile.

We need to move towards adopting operational stage.
Move towards to the transient habitability timeline, from the disaster and evacuation to definitive solutions.

Almeida, V., Cortéz-Barbosa, J., Nivaldo, J., Gava, M., Laroca, C., & Fábio, S. (2016). Woodframe: light framing houses for developing countries. *Revista de La Construcción, 15*(2), 78–87. https://doi.org/10.4067/S0718-915X2016000200008

American Wood Council. (2014). *Component additive method (CAM) for calculating and demonstrating assembly fire endurance.* American Wood Council. Retrieved from http://www.awc.org/pdf/codes-standards/publications/dca/AWC-DCA4-CAM-1007.pdf

APA – The Engineered Wood Association. (2014). *Advanced framing - Construction guide, M400a, 20*. Retrieved from http://www.apawood.org/data/sharedfiles/documents/m400.pdf

Bobadilla, A., Diaz, M., Figueroa, R., & Arriagada, R. (2014). Proposal of Acceptable Air Tightness Classes for Buildings in Chile. *Revista de la Construcción, 13*(1), 15–23. https://doi.org/10.4067/S0718-915X2014000100002

Bustamante, W., & Rozas, Y. (2009). Guia de Diseño para la Eficiencia Energética en la Vivienda Social (Ministerio). Santiago: Universidad de Chile. Facultad de Arquitectura y Urbanismo, Instituto de la Vivienda, Universidad Federico Santa María, Fundación Chile. https://doi.org/10.1017/CBO9781107415324.004

Cardona, O. (2008). Medición de la gestión del riesgo en América Latina. *Sostenibilidad, Tecnología Y Humanismo UNESCO,* (3), 1–20.

Castro, C., Sarmiento, J. P., Edwards, R., Hoberman, G., & Wyndham, K. (2017). Disaster risk perception in urban contexts and for people with disabilities: case study on the city of Iquique (Chile). *Natural Hazards, 86*(1), 411–436. https://doi.org/10.1007/s11069-016-2698-x

Corporación de Desarrollo Tecnológico. (2015). *Manual Acondicionamiento Térmico. Corporación de Desarrollo Tecnológico*. Santiago. Retrieved from http://www.energia.gob.cl/sites/all/modules/custom/energia_core/resources/Manual_Acondicionamiento_Termico.pdf

Escorcia, O., García, R., Trebilcock, M., Celis, F., Echeverría, E., & Sánchez, R. (2013). Validación del reacondicionamiento térmico de viviendas para la reconstrucción pos-terremoto 2010: Dichato, Chile. *Revista de la Construcción, 12*(2), 54–71. https://doi.org/10.4067/S0718-915X2013000200005

Flores, O. (2015). Paisajes en emergencia: Transformacion, adaptacion, resiliencia. *Revista INVI, 30*(83), 9–17. https://doi.org/10.4067/invi.v30i83.978

Garay, R. M. (2015). Vivienda de emergencia Reflexiones a partir del terremoto del 27F. *Revista INVI, 30*(83), 213–221.

Garay, R. M., Pfenniger, F., Tapia, R., & Larenas, J. (2014). *Viviendas de emergencia, criterios técnicos y reglamento para estándares de calidad de viviendas y conjuntos de viviendas en asentamientos provisorios*. In Universidad de Chile Viviendas de Emergencia: Manuales de Fabricación, Instalación, Especificaciones técnicas y Reglamentos. (p. 48). Universidad de Chile.

Garay, R. M., Pfenniger, F., Tapia, R., & Larenas, J. (2016). *Criterios técnicos y reglamento para estándares de calidad de viviendas y conjuntos de viviendas en asentamientos provisorios*. In Reflexiones sobre la emergencia : territorio, vivienda e institucionalidad en contextos de desastres socioambientales Fundación Vivienda (pp. 120–140). Libro ReflexionesLibro Reflexiones sobre la emergencia : territorio, vivienda e institucionalidad en contextos de desastres socioambientalesFundación Vivienda.

González, M., Vásquez, L., & Hernández, G. (2016). *Guía práctica para la construcción de viviendas de madera con sistema plataforma*, (185), 126. Retrieved from http://biblioteca.infor.cl/DataFiles/26793.pdf

INGEPANEL. (2011). *Structural Insulated Panel Guide*, 5–6. Retrieved from http://www.ingepanel.cl/pdf/productos.pdf

Instituto Nacional de Normalización. (1997). *NCh9 35/1:1997 Prevención de incendio en edificios - Ensayo de resistencia al fuego - Parte 1: Elementos de construcción en general.* Santiago.

Instituto Nacional de Normalización. (2007). *NCh 853. Acondicionamiento térmico - Envolvente térmica de edificios - Calculo de resistencias y transmitancias térmicas*. Instituto Nacional de Normalización, Chile. https://doi.org/10.1017/CBO9781107415324.004

Instituto Nacional de Normalización. (2016). *NCh 3393. Paneles estructurales aislantes – Requisitos de fabricación.* Santiago. Retrieved from http://ecommerce.inn.cl/Ficha_Producto/?p=NCh3393:2016

Mahuzier, J. A. (2017). *Requerimientos sobre la resistencia al fuego y traspaso de humos en puertas usadas en los edificios*. Universidad de Chile. Retrieved from http://repositorio.uchile.cl/bitstream/handle/2250/144282/Requerimientos-sobre-la-resistencia-al-fuego-y-traspaso-de-humos-en-puertas-usadas-en-los-edificios.pdf?sequence=1&isAllowed=y

Ministerio de la Vivivenda. (2017). *Resumen de modificaciones y rectificaciones de la Ley General de Urbanismo y Construcciones*. Diario Oficial. Retrieved from http://www.minvu.cl/incjs/download.aspx?glb_cod_nodo=20061113162221&hdd_nom_archivo=Ley General Mayo 2017 (Ley 21.014 publicación D.O.pdf

Ministerio de Vivienda y Urbanismo. (2014). Listado oficial de comportamiento al fuego de elementos y componentes de la construcción del Ministerio de Vivienda y Urbanismo. Minvu-Ditec, edición 14, 1–233. Retrieved from http://www.minvu.cl/incjs/download.aspx?glb_cod_nodo=20070606164405&hdd_nom_archivo=Listado Oficial de Comportamiento al Fuego E14-1_2014.pdf

Ministerio de Vivienda y Urbanismo. (2016). *Estándares de construcción sustentable para viviendas de Chile Tomo I: Salud y bienestar*. División Técnica. Retrieved from http://csustentable.minvu.gob.cl/wp-content/uploads/2016/11/ECSV_1.pdf

Pérez, M. Á. (2016). *Seminario Normativa y Resistencia de Materiales - Resistencia al Fuego de Materiales*. (C. C. de la C. Corporación de Desarrollo Tecnológico, Ed.). Santiago: Universidad de Chile. Facultad de Arquitectura y Urbanismo, Instituto de la Vivienda. Retrieved from http://www.cdt.cl/download/10909/

Secretaría General de la Comunidad Andina. (2017). Estrategia andina para la gestión del riesgo de desastres-Decisión 819. Comisión de La Comunidad Andina. Retrieved from http://www.comunidadandina.org/StaticFiles/2017522151956ESTRATEGIA%20ANDINA.pdf

Sehnbruch, K. (2017). The Impact of the Chilean Earthquake of 2010: Challenging the Capabilities of the Neoliberal State. *Latin American Perspectives, 44*(4), 4–9. https://doi.org/10.1177/0094582X17705859

Tecnopanel. (2008). *Características tecnicas panel SIP Tecnopanel.* Retrieved from http://www.especificar.cl/fichas/sistema-de-paneles-sip

Wagner, M. (2017). E*l desafío está ahora en la industrialización de los sistemas constructivos en madera*. Retrieved August 27, 2017, from http://www.madera21.cl/?p=6865