	<p>THERMAL PERFORMANCE UNDER WINTER CONDITIONS OF A REFLECTIVE INSULATION BASED WALL PANEL FOR EMERGENCY HOUSES IN CHILE</p>	<p>CONSTRUCTION TECHNOLOGY</p>
<p>RESEARCH ARTICLE</p>	<p>Miguel Angel Galvez Huerta; Nina Hormazabal Poblete; Pablo Sills Garrido; Tomás Gil Lopez; Rubén Felices Puertolas</p>	<p>Prefabricated Buildings</p>


THERMAL PERFORMANCE UNDER WINTER CONDITIONS OF A REFLECTIVE INSULATION BASED WALL PANEL FOR EMERGENCY HOUSES IN CHILE

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COMPORTAMIENTO TÉRMICO EN CONDICIONES DE INVIERNO DE PANEL DE FACHADA BASADO EN AISLAMIENTO REFLECTIVO PARA VIVIENDAS DE EMERGENCIA EN CHILE

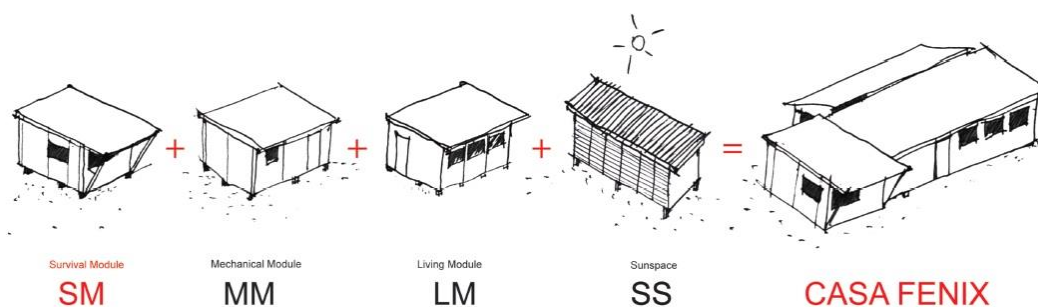
<p>ABSTRACT:</p> <p>Casa FÉNIX solution for the emergency is a modular and progressive construction system based on a prefabricated timber structure that provides a great variety of growing possibilities. This initiative, originally conceived to take part in the 2014 Solar Decathlon Europe Competition, is central to many research activities carried out by the Department of Architecture of the Santa María Technical University of Valparaíso, Chile, the most recent of which is the FONDEF IDeA project "Systematization of non-structural components for an emergency house" Within the framework of this research, a lightweight, easy-to-assemble, low-cost wall solution has been developed. It consists on a sandwich panel composed of an expanded polystyrene (EPS) core and a cardboard honeycomb reinforcement on both sides, which constitutes air chambers. The inclusion of reflective layers on each of the sides of the air chambers significantly increases the thermal resistance of the element with no significant weight increase.</p> <p>The work addresses the winter performance of the aforementioned wall element variations, characterized by their thermal transmittances, U. The study has been carried out with analytical (UNE-EN-ISO 6946) and computational (THERM) models, which have been compared and validated by means of experimental tests.</p> <p>Transmittance tests carried out for different variations of the solution show compliance with the regulatory requirements for the three climatic zones of central Chile that gather 60% of the country's population. From these data a complete set of alternatives have been developed in order to respond to the different thermal demands of nine climatic zones of the country, that range from the aridity of the Atacama Desert to the cold Patagonian regions</p> <p>Keywords: Vivienda de emergencia, Panel de fachada, Aislamiento reflectivo, Simulación térmica. Transmisión de calor.</p>	<p>RESUMEN:</p> <p>La solución para la emergencia Casa FENIX es un sistema modular y progresivo basado en una estructura de madera de rápido montaje y muy versátil en cuanto a su crecimiento y capacidad de extensión. Esta iniciativa, inicialmente pensada para participar en la competencia Solar Decathlon Europe (SDE) 2014 se encuentra en el centro de varias investigaciones en las que se encuentra inmerso el grupo de investigación que la desarrolla. Entre ellas, en el marco del proyecto FONDEF IDeA en dos etapas "Sistematización de componentes no estructurales para vivienda de emergencia" se ha desarrollado una solución de fachada ligera, de fácil montaje y bajo costo a base de panel sándwich compuesto de un núcleo de poliestireno expandido y un refuerzo de honeycomb de cartón por ambas caras, configurando cámaras de aire. La inclusión de hasta cuatro láminas reflectantes en las paredes de las cámaras permite aumentar considerablemente la resistencia térmica del conjunto sin incrementar su peso. Ensayos de transmitancia realizados para distintas variantes de la solución demuestran el cumplimiento de las actuales exigencias normativas para las tres zonas climáticas del centro de Chile que agrupan el 60% de la población del país. A partir de estos datos se han elaborado las variantes necesarias para responder a las exigencias de las 9 zonas climáticas del país, que van de la aridez del desierto de Atacama a los fríos patagónicos. El trabajo que se presenta ahora se centra en analizar el comportamiento en invierno de las variantes del elemento constructivo descrito, caracterizadas por su transmitancia térmica, U. El análisis se ha llevado a cabo con modelos analíticos (norma UNE) y computacionales (software THERM), cuyos resultados se han comparado y validado por medio de ensayos de laboratorio. Ensayos de transmitancia realizados para distintas variantes de la solución demuestran el cumplimiento de las actuales exigencias normativas para las tres zonas climáticas del centro de Chile que agrupan el 60% de la población del país. A partir de estos datos se han elaborado las variantes necesarias para responder a las exigencias de las 9 zonas climáticas del país, que van de la aridez del desierto de Atacama a los fríos patagónicos.</p> <p>Palabras clave: Emergency housing, light-weight wall panel, reflective insulation, thermal simulation, heat transmission</p>
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1.- INTRODUCTION

The solution Casa FENIX [1] for emergency situations is a flexible modular and progressive system built on a prefabricated timber structure that provides a great variety of growing possibilities (figure 1). The benefits of the solution reside on the fact that the solution does not work exclusively for the occasional problem of an emergency, but it can also become the beginning construction of a permanent home, complying with the habitability standards required to any construction of this kind. In this way Casa FENIX is three stages of an incremental house reconstruction process that takes place after a catastrophe: stage 1 - emergency, with the surviving module (SM), lasting for 6 months; stage 2 - relief the mechanical module (MM) for installations, lasting for 2 years; stage 3 -reconstruction, the duration will depend on the magnitude of the catastrophe, it includes other modules, such as the living module (LM) and the sunspace (SS), the LM is to be replicated as many as needed by the victims.

Fig. 1: Casa Fenix: concepts of modularity and progressivity



This initiative, initially designed to participate in the Solar Decathlon Europe 2014 competition, is located in the center of several research activities and grants allocated by the research group involved in it: a first result is a specific solution for the reconstruction after the urban fire of Valparaíso 2014 [2].

Currently, the team of the project is currently working on the envelope and on an industrialized technical wall embedded with all the facilities for the house; both components developed within this FONDEF IDeA project called "Systematization of non-structural components for emergency housing". The framework of this research focused on the design of the facade system composed of non-structural panels that could be easily assembled and disassembled in a short time. In this sense, the main requirements were lightness, modularity, low cost, and good thermal performance. The final adopted solution was a panel of 0.60 m by 2.40 m composed of a core of expanded polystyrene with air chambers formed by a stiffed grid (made of 2 to 5cm cardboard honeycomb), these chambers are attached to one or both sides. The contact surfaces between the insulated core and the chambers are made of veneers of kraft paper and polyethylene, coated to the inside of the chamber by a layer of aluminum foil. This solution considerably increases the level of insulation thanks to the radiant properties of the foil inside of the chamber [3, 4]. The outermost layers are made of plywood to the interior and a metal sheet to the outside, although these finishings can vary according to aesthetic considerations. The panel is framed with a waterproof insulation material of high density extruded polystyrene (figure 2).

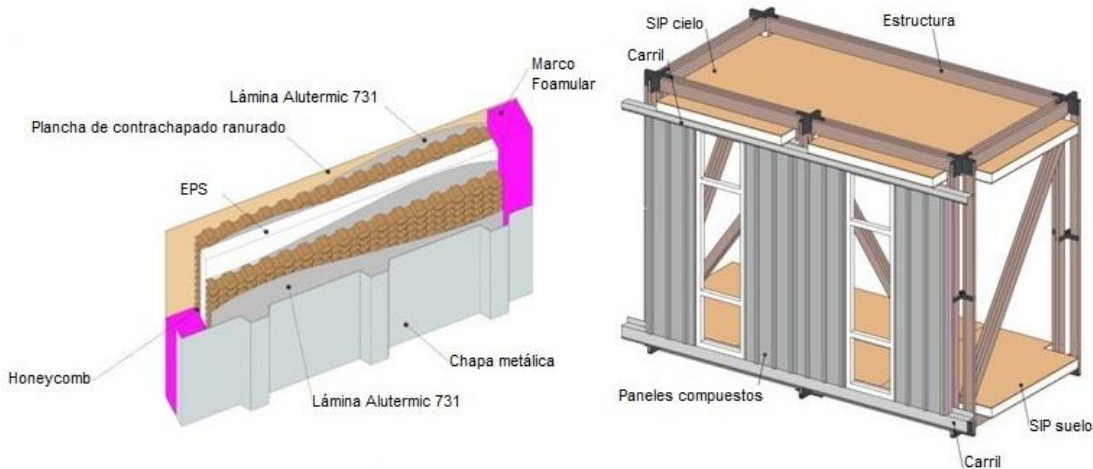


Fig. 2: Envelope panel proposal and assembly component's system. Source: C. López [5]

To minimize thermal bridges, the vertical junction between panels are mortise and tenon type formed in the perimeter frame. The component has a joint pressure system to secure the air and water tightness and allowing an easy assembly and disassembly from the interior. In order to be able to adapt this solution to the different Chilean climate zones, the research has applied the methodology described in the next section.


2.- EXPERIMENTAL DEVICE

To begin, three variants of the described panel solution were studied and tested to obtain the thermal transmittance for each of them. The results were used to validate the subsequent analytical and computational models. These procedures are aidful to the design process in order to adopt the best solution to comply with requirements for the nine different Chilean climate zones, both in conditions of winter (what is done in this work) as summer (what it is expected to be carried out in future research).

2.1. DESCRIPTION OF THE ANALYZED VARIANTS

First, three variants of the panel solution were identified (figure 3) as most appropriated to cover most part of the Chilean territory according to the current thermal regulations [6].

- Variant 1: Two layers of honeycomb, 4 cm and 2 cm thick each, one without insulation core. These grids are separated by a Kraft paper with reflective sheets on both sides.
- Variant 2: A layer of a 4 cm honeycomb outside and a 2 cm expanded polystyrene insulation core. The insulation includes a vapor barrier to the inside and reflective sheet towards the grid.
- Variant 3: Two layers of 2 cm honeycomb on both sides of a 2 cm expanded polystyrene insulation core with reflective sheets towards the chambers.

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1. 9 mm grooved plywood panel Araucopy Noble
2. Honeycomb cardboard Celhex e. 0,5 mm
3. XPS insulation (d. 35 kg/m³)
4. EPS insulation (d. 20 kg/m³)
5. Metal sheet 5V (e. 0,5 mm)
6. Alutermic 731 e. 0,08 mm composition:
 - Aluminium 18,9 g/m² (e. 0,007 mm), facing the air chamber
 - Polyethylene 15 g/m² (e. 0,05 mm)
 - Kraft 60 g/m² (e. 0,02 mm)

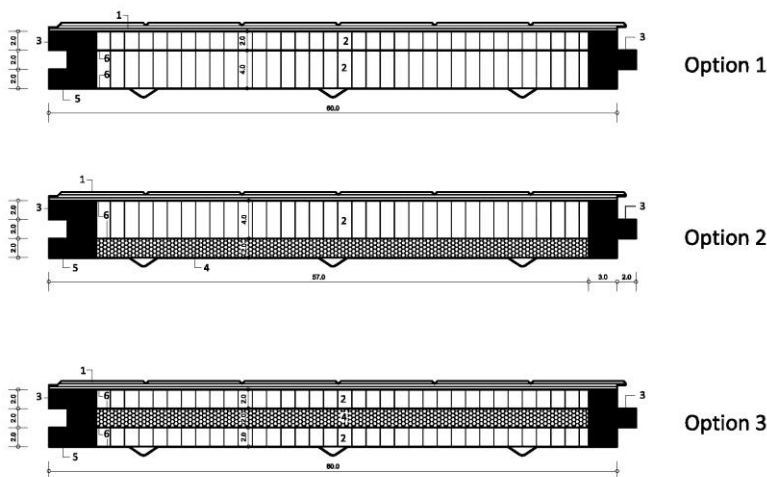


Fig. 3: Panel options composition.

2.2. EXPERIMENTAL TESTS


The thermal transmittance of the described panels was obtained experimentally according to the procedure described in the specific Chilean standard [7]. A brief summary of this procedure is described as follows: To perform this test the panels are mounted in a 110 x 150 cm prefabricated frame. The fastening to the edge is made with polyurethane foam and the joints between panels were sealed with silicone and 3M tape. For this case, the panels were assembled horizontally at the joints. Acknowledging the low mechanical strength, a wooden frame was built to stiffen the central part of the panel which is the one that was actually tested.

This frame is put into a locked chamber, with two 100 x 100 cm parallel walls which surfaces are subjected to the outside and inside air conditions reproduced by a low power cooling device and some electrical resistances, respectively. The air temperatures are measured with eight thermocouples on each side. The same number and distribution of thermocouples are placed on the surfaces of the panel to be tested. When the temperature measurements of the walls have stabilized (which may take days) the heat flow is measured, from which the transmittance is obtained. The locked chamber has an insulating perimeter ring intended to guarantee there is no heat flow in that direction and that the entire flow is perpendicular to the wall. To ensure this condition, the test is carried out by inserting the locked chamber in a larger one, in which the losses are known and with them, the value obtained is corrected.

2.3. ANALYTICAL CALCULATION OF TRANSMITTANCES

The analytical estimation of the thermal resistances of this constructive element was carried out according to the calculation method specified in Annex B of the UNE-EN-ISO 6946: 1996 [8].

The values of the thermal conductivities [9, 10] and emissivities [11] of the three solutions used in the calculations are summarized in the following table (Table I):

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Material	Thermal conductivity (W/mK)	Density (kg/m ³)	Emissivity (-)
Plywood	0,13	(-)	0,8
Alutermic 731	(-)	(-)	0,2
EPS	0,037	20	0,8
XPS	0,037	35	0,8
Metal sheet	50	(-)	0,2

Table I: Construction materials properties

2.4. COMPUTATIONAL SIMULATION

To analyze the panels with simulation, despite the initial intention to use a CFD model in ANSYS as is the usual practice of the authors [12,13], at last we used a finite element program, THERM [14], a calculation software that allows a two dimension analysis, on one side the transmittance of walls and, at the same time it visualize the thermal bridges of the building. Regarding its potential, it is highlighted that this program allows incorporating any type of material when the conductivity and emissivity are known. In addition, the calculation of the transmittances allows incorporating the indoor and outdoor air resistance coefficients, temperatures and direct radiation that might impact on one of the sides. It is appropriate to indicate that the results obtained in the air chambers are more accurate than those obtained through the analytical procedure, since it adjusts the emissivities of the adjacent materials and, it depends on the actual temperature obtained from the simulation, it gives a precise value of the conductivity coefficient of the air chamber.

In relationship to the adjustments that need to be made when using the program, the following stand out:

- The thickness of the Alutermic layer has had to be adjusted to 0.1 mm since it is the lowest value that the program admits. Even so, it is 100 times less compared to other programs, such as HLUC and CE3X, used in Spain. The resistance of the Alutermic has been obtained as total resistance of the three materials that compose it.
- The Alutermic layer has two sides with very different emissivity. To address that it was necessary to incorporate two materials with equal conductivity and different emissivity in panel 1. It is the case where two air chambers are separated by the Alutermic, so the results were completely incoherent when running it in any other way.
- The materials used in the simulations have the same conductivities and emissivities to those specified in the analytical calculation (Table 1). Only in the case of the Alutermic, the emissivities used have been modified to 0.1 and 0.8, instead of 0.2 and 0.8.
- All panels have been analyzed by the conduction method in one direction, assigning as an external boundary condition 5°C and 25 W/m²K, and as an internal condition 20°C and 7,692 W/m²K.

3.- RESULTS AND DISCUSSION

The comparative analysis carried out has been divided into three phases: First, a panel of one linear meter was analyzed by comparing the results of the tests, the analytical calculation and the THERM simulation; second, this simulation has been used to evaluate the performance of a complete panel incorporating EPS sides; and third, with the same tool, the result was analyzed replacing the Alutermic 731 for layer with an emissivity value of $\epsilon = 0.80$ on the walls of the air chambers.

The results obtained are shown in the following figures:

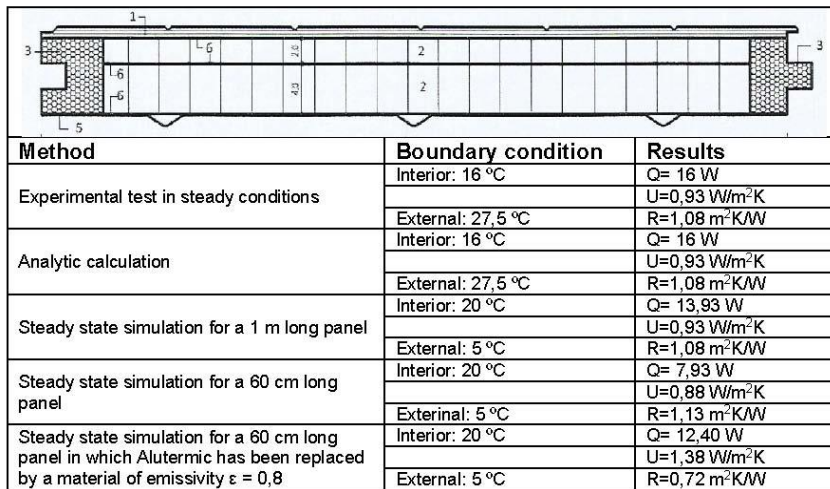


Fig. 4. Results for Panel 1.

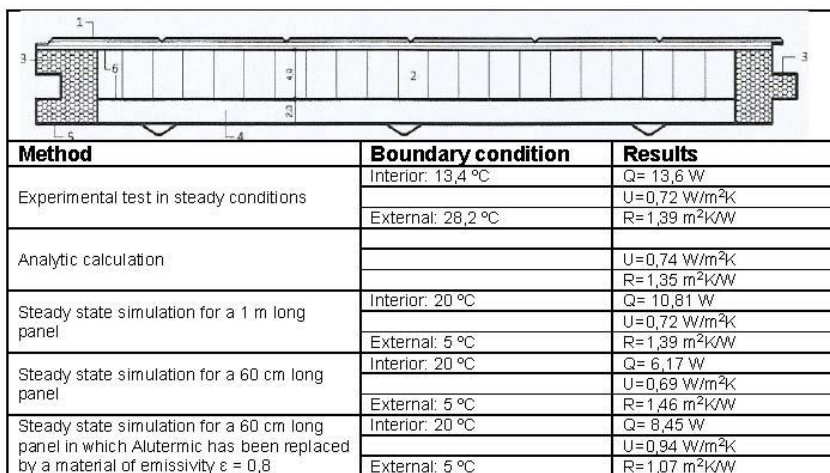


Fig. 5. Results for Panel 2.

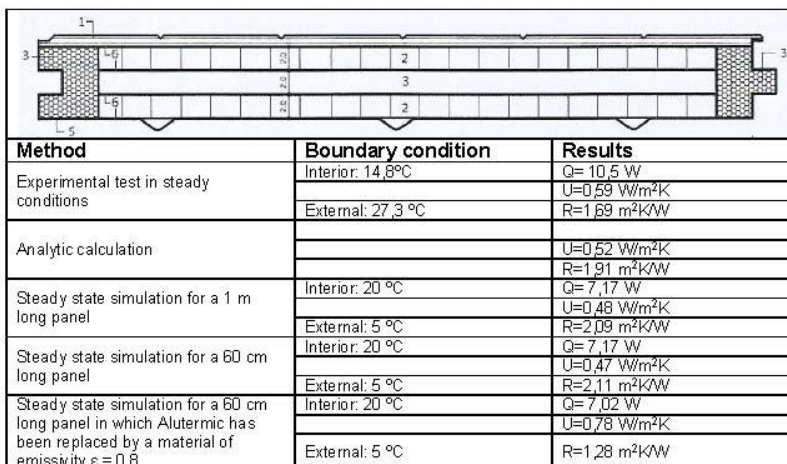



Fig. 6. Results for Panel 3.

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For simulations performed on a linear meter, the transmittance values were very close to those obtained with the tests. In fact, panels 1 and 2 have the same results in the simulation and the test. For the analytical calculations, if the emissivity value of 0.2 is changed to 0.1, the same transmittance values will be obtained in the simulation, and therefore, in the test. The use of different emissivity for Alutermic aluminum is based on the literature review on the emissivity for polished aluminum, finding the value of about 0.1.


These two reflections lead to the anomalous result obtained for panel 3.

If the simulation runs with the emissivity value of 0.2, the result would be a transmittance of 0.52; the same result of the analytical calculation. Or vice-versa, if for the analytical model the emissivities of the chambers are 0.1, the transmittance will be 0.48, matching the result obtained for the simulation.

The sum of these considerations leads us to think that panel 3 has introduced some erroneous variable, assuming that certain deficiencies occurred in the elaboration of the sample tested: A first possibility is that in the test the Alutermic disposition was not set with the aluminum side facing the chamber in at least one of the four positions of panel 3. If this was the case, the transmittance of the panel would approach the values obtained in the test. However, the most reasonable hypothesis is that in the test an XPS core was used instead of an EPS core, assuming that these materials have different conductivities. Certainly, although in table 1 the characteristics indicated, both conductivities are equal (0.037 W/mK), since both materials have different densities, they should have different conductivity. In fact, the conductivity necessary for both the analytical calculations and the simulation to give the same result as the test is 0.029 W/mK. This value matches the specifications of the commercial XPS for the indicated density [15]. For the three panels, the variant 1 on a complete panel that includes the EPS sides confirms that its disposition on the sides slightly decreases the transmittance, which is a good solution for the side finishing of the panels.

4.- APPLICATION PROPOSALS

The experimental validation of the analytical method of the norm UNE allows using this method to propose in a simple way numerous variants of the construction panel solution for the climate zones considered in the Chilean thermal regulations [16] as in other documents of good construction practices used in Chile [17, 18]. In this respect, the following proposal is made (Table II):

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Thermal Zone	Core composition ⁽¹⁾			Alutermic position ⁽²⁾	R (m ² K/W)	U ⁽³⁾ (W/m ² K)	
	External	Middle	Interior			U _{limit}	
A	HC 4	(-)	HC 2	2	0,967	1,034	2,10
B	HC 2	EPS 3	HC 3	2, 3 y 4	2,077	0,482	0,50
C	(-)	EPS 2	HC 4	3	1,262	0,793	0,80
D	HC 2	EPS 2	HC 2	2 y 3	1,707	0,586	0,60
E	HC 2	EPS 4	HC 2	3	2,024	0,494	0,50
F	HC 2	EPS 4	HC 2	2, 3 y 4	2,335	0,428	0,45
G	HC 2	EPS 5	HC 3	2, 3 y 4	2,617	0,382	0,40
H	HC 4	EPS 6	HC 2	1, 2 3 y 4	3,357	0,298	0,30
I	HC 3	EPS 6	HC 3	1, 2 3 y 4	2,979	0,366	0,35

(1) The acronyms used in the table have the following meanings:

- HC: Honeycomb cardboard Celhex layer. The number stands for the thickness, in cm
- EPS: Expanded polystyrene, density: 20 kg/m³. The number stands for the thickness, in cm

(2) The numbers that indicate the position of the reflective layer stand for the following limits:

- Position 1: Metal sheet and external HC limit
- Position 2: External HC and EPS limit
- Position 3: EPS and interior HC limit
- Position 4: Interior HC and plywood limit

(3) The thermal transmittances have been calculated with the aforementioned core composition and the following finishing layers

- External: 0,3 mm zinc sheet
- Interior: 9 mm grooved plywood panel Arucopy


Table II: Proposal for nine climatic zones to comply with Chilean code.

Given the advantages offered by reflective insulation in the chambers, it shows that the thickness of the construction of the panel (maximum 12 cm) are considerably smaller than those that would be obtained through the use of traditional insulation, based on heat conduction [19].

Like most thermal regulations, the Chilean one is designed for winter and consequently focused on improving the levels of insulation and the airtightness of buildings. However, these demands can contribute to the overheating of spaces in summer, a problem that is exacerbated in the current climate change scenarios. Thus, the methodology used in this work can become a simple analysis and design tool to optimize the performance of envelopes with air chambers and reflective insulation in summer conditions, when it becomes important the effect of solar radiation [20].

5.- CONCLUSIONS

A computational simulation of a simple 2D model has been used to determine the thermal transmittance of a light envelope panel based on reflective insulation, for which three different constructive variants were developed, modeled, tested and analyzed. The obtained thermal transmittance results agree with those of experimental tests carried out by the procedure of the locked chamber. There is also agreement with the results obtained with the analytical method of the standard UNE-EN-ISO 6946: 1996.

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This concordance of results allows having a simple and reliable tool for the design of an envelope panel based on reflective insulation.

This tool has been applied to the design of specific solutions for the nine Chilean climate zones, resulting in a considerably lower thickness for an envelope panel than those panels with conductive insulation. The methodology used in this work can also become a design tool for a composed envelope with air chambers and reflective insulation in summer conditions.

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