

## 566: Thermal and energetic analysis of a precast panel for industrial buildings

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### Abstract

On the basis of Directive 2002/91/EC the energy savings in the buildings sector (residential, commercial, industrial, etc...) cannot be postponed; about 40% of the total energy consumption takes place in buildings, which is the highest percentage among energy consumers. The building design have to take into account all issues related to energy performance, and in special way, all those related to building energy use for heating, ventilation, cooling, lighting.

Concrete precast panels, often used in industrial building, are currently used, in Italy and worldwide, also for wider application (e.g. commercial building, warehouse,..) and so this claims for their better energetic and thermal performances to ensure energy savings and well-being, achieving the function of separating the controlled indoor environment from the uncontrolled outdoor environment.

This paper present the results of a numerical (using 3-D finite difference) and in-situ (experimental) analysis of a lightweight and thermal barrier panel designed to improve thermal and energetic performances respect to an actual lightweight panel employed in an industrial building located in the southern part of Italy.

Keywords: precast concrete panel, thermal barrier, energy saving, U-value, thermal inertia, test facility, in-situ experimental analysis.

### 1. Introduction

The thermal performance of a building may be defined as the result of the process whereby the design, layout, orientation and construction materials of the building modify the prevailing outdoor climate influencing the indoor climate. In a building this is generally perceived by the occupants in terms of the extent to which the building seems cool in an hot summer and warm in cold winter weather, taking into account the amount of heating or cooling required to create comfortable thermal conditions [1].

As well more than half of the true total costs incurred during the economic life of a building may be attributable to operating and energy costs; about 90% of the energy used during a building's life is attributed to heating, cooling and other utilities, the remaining 10% is attributed to manufacturing materials, construction, maintenance, replacement of components and demolition [2].

Precast concrete panels can be designed to provide a high degree of energy efficiency, providing an economic initial investment with a continuing payback.

Architectural precast concrete systems can vary in complexity from simple conventional systems to composite sandwich assemblies that function as the entire environmental shell.

Conventional architectural precast traditionally was a single exterior wythe which incorporated the desired finish, but for concrete being an appropriate material for thermal design and energy efficiency in a building, it needs to be fully insulated from the outside climate: this is

obtained with sandwich architectural precast incorporating thermal insulation between an exterior architectural wythe and an interior structural wythe. The insulation contributes to reduce heating and cooling costs: the ability of a building component, such as a wall, to transmit heat is expressed as the U-value of the component [3].

But also thermal mass of concrete saves energy year-round by reducing daily temperature swings. The heat absorbing capacity and the insulating property determine the heat storage capacity of a building. The relative importance of each of these properties in providing a pleasant indoor thermal environment depends on the climate of the area in which the building is built.

To deep investigate the abovementioned issues, and define them at the initial stage of design process or in a retrofitting operation, many software tools are nowadays available; these tools can lead effective information on main parameters that influence panel performance and so they can define requirements necessary to improve energetic performance in term of geometric parameters and thermal insulation required. Nevertheless the results of numerical analysis cannot be considered as exhaustive, and they have to match with a suitable set of experimental data both for the verification of the assumptions made then for the software calibration. To this aim, starting from an actual panel system used for industrial building application, the paper presents the results of an R&D project related to a numerical and in-situ (experimental) analysis performed to improve

thermal and energetic performances obtained with a lightweight and thermal barrier panel.

## 2. Methodology

The starting panel system is used for an industrial building cladding located in the southern part of Italy, Avellino (latitude: 40° 54' 55" and longitude 14° 47' 22"). The climate of Avellino, a town located inland about 30 miles east of Naples, is markedly different than that of Naples coast: it is separated from Naples by hills that become the Apennine Mountains and its weather is comparatively cooler and similar to that of northern Italy. It has colder average temperatures, together with elevations of about 1,800 feet, and great day/night temperature variations; following the Italian standardization it is characterised by a 1742 heating degrees day. The building is a low-rise type industrial building that is one story in height and is rectangular in plant (163 x 58 m, height 10,76 m):

In figure 1 a sketch of panel is drawing; it is a typical precast concrete reinforced panel for wall application with maximum dimension of 10.70 m height and 2.0 m width, and an overall panel thickness of 0.16 m; the panel is provided with a factory-made rigid foam insulation of 1.20 x 1.30 m of surface and 0,08 m of thickness that provides to lighten the structure and added R-value in the wall. Foam insulation is made with expanded polystyrene; these boards are lightweight, and provide acoustical insulation and structural support that is primarily achieved by means of a steel mesh reinforcement. A typical transmittance value of a precast concrete reinforced panel is 2.00 W/m<sup>2</sup>K [4].

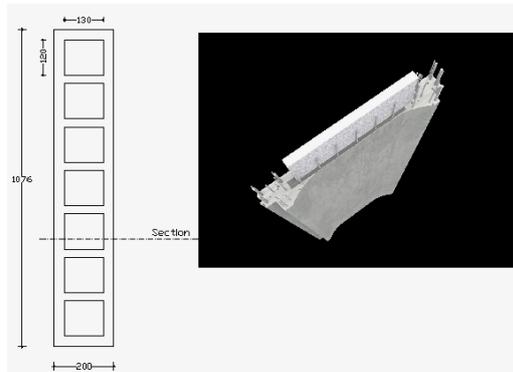


Fig 1. Sketch of panel

In order to assess the performance of several panel prototypes a “test facility” has been set up for an in-deep investigation of thermal conductivity of single material and transmittance value of the panel whole assembly. This test facility (figure 2) is characterized by two identical rooms in which are placed two electric heat pumps to keep a prefixed air temperature value, this allows to perform:

- measurements of thermal conductivity of samples with dimension of 1.40 x 1.40 m and maximum thickness of 0.10 m (zone 1) setting appropriate temperature differences between the rooms;

- measurement transmittance value and infrared thermal imaging analysis of the panel prototypes (zone 2).

An external view of the “test facility” is reported in figure 3.

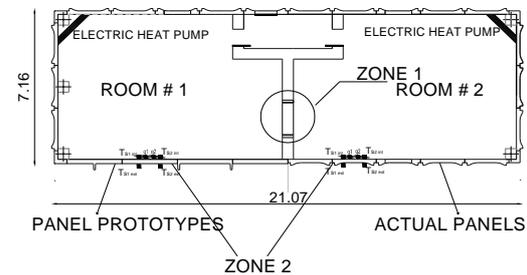


Fig 2. Plan view of test facility for measurements of samples thermal conductivity and panel prototypes transmittance value



Fig 3. External view of test facility

The measurement system of samples thermal conductivity and panel transmittance is performed by the heat flux meter Trsys01 (figure 4): it can be used for thermal transmittance measurements of building elements according to ISO 9896 and includes two heat flux sensors type HFP01 (sensitivity 50  $\mu$ V/(W.m<sup>2</sup>), range -2000÷2000 W/m<sup>2</sup>, response time  $\pm$  3min, accuracy  $\pm$  5%), two pairs of matched thermocouples type KX (range -30 ÷ 80 °C, accuracy  $\pm$  2 °C), Measurement and Control Unit (MCU) with an adapter for 110/230 VAC operation. This system is connected to a PC, with PC208W software as user interface, to unload and record data by a PC (ISO 9869) [5].

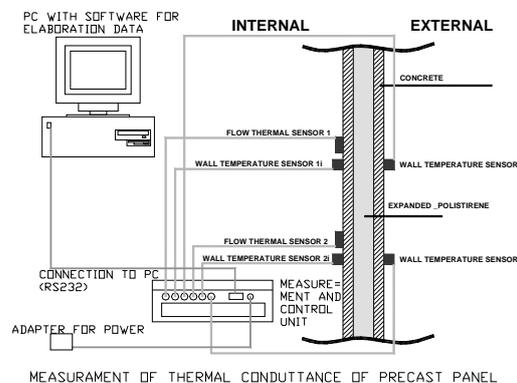


Fig 4. Transmittance value measurement

In an ideal situation the internal and external temperatures would be constant, giving a steady

state condition and accurately determined transmittance value. In practice steady state conditions do not occur, however, and considerations has to be given to the variations in temperatures and heat flow before transmittance value can be determined reliably. Instantaneous measurement of the transmittance value, therefore, would not be practicable for this purpose and it is necessary to measure the heat flow and temperatures over several days in order to achieve a reliable result. In theory, the transmittance value of an element is calculated from equation 1:

$$\text{eq. 1} \quad K_m = \frac{\int q(t) \cdot dt}{\int [T_i(t) - T_e(t)] \cdot dt}$$

provided that the integral is summed over a long period of time. In the above, q is the heat flux [W/m<sup>2</sup>], T<sub>i</sub> is the internal surface temperature, T<sub>e</sub> is the external surface temperature, t is time and K<sub>m</sub> is the transmittance value. If n measurements are carried out over uniform time intervals then a good approximation is (equation 2):

$$\text{eq. 2:} \quad K_m = \frac{\sum_n q}{\sum_n (T_i - T_e)}$$

This approximation only holds good provided that the summation is taken over a sufficient period of time and provided that thermal storage effects are not too large [6].

In order to validate the transmittance value obtained by in-situ measurement and to design panel prototypes with satisfactory thermal performance the software "COMSOL Multiphysics modelling" is used: it is able to define complex heat-transfer 3D problem solving differential equation with finite difference method and also to implement full multiphysics capabilities to couple heat transfer with moisture transfer.

### 3. Analysis and results

The reinforced panel actually used represented in figure 2 is a typical heat transfer 3-D problem, solvable with Comsol Multiphysics: starting from thermal and physical properties of the materials (table 1) and setting up boundary conditions in steady state, software processes the 3-D heat flux field shown in figure 5.

In order to improve the insulating property of the current reinforced panel an additional sandwich panel has been designed with enclosed a thermal barrier and a larger overall thickness. A side view of this panel is shown in figure 6: the two layers of concrete have each a thickness of 0,05 m, they are separated by a central layer of uninterrupted rigid insulation of 0,10 m.

The U-value calculated is 2,29 W/m<sup>2</sup>K.

Table 1. Thermal and physical properties of the materials

Material	ρ - Density [kg/m <sup>3</sup> ]	λ - Thermal conductivity [W/mK]	c <sub>p</sub> - Specific Heat [J/kgK]
Concrete	2400	1,91	880
Expanded polystyrene	15	0,045	1200

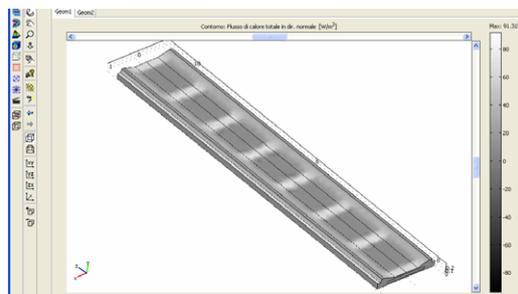


Fig 5. 3-D heat flux field for the current reinforced panel

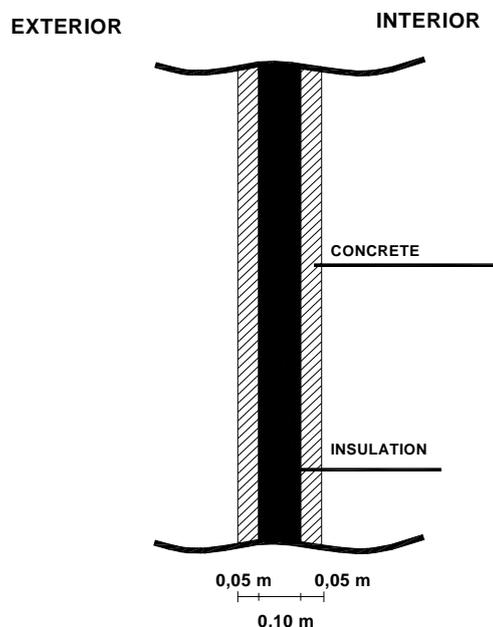


Fig 6. sandwich panel with thermal barrier

Two types of this panel have been considered, characterized by two several insulating materials to provide thermal barrier:

1. expanded polystyrene,
2. expanded clay.

Thermal and physical properties for the first are quoted in table 1, for the second are:

- density: 1000 kg/m<sup>3</sup>,
- thermal conductivity: 0,31 W/mK,
- specific heat: 880 J/kgK.

The scheme of the panel reported in figure 6 is a typical one-dimensional heat flux problem: heat flux field appears homogeneous over the whole surfaces normal to the temperature gradient.

The theoretic U-value is evaluated carrying out one-dimensional hypothesis and is reported in table 2. Also the percentage decrement obtained

respect to the starting reinforced panel U-value is reported.

Table 2. U-value and percentage decrement for analyzed panel

Panel	U-value [W/m <sup>2</sup> K]	U-value decrement [%]
Reinforced panel	2,29	-
Thermal barrier panel with expanded polystyrene	0,41	-82,1%
Thermal barrier panel with expanded clay	1,84	-19,6%

The results reported in table 2 show that the optimum thermal isolation performance is obtained with a sandwich panel incorporating expanded polystyrene, because of its very low thermal conductivity value.

Nevertheless U-value performance does not take into account dynamic behaviour of the panel or its capacity to store thermal energy. For this reason two parameters are used to evaluate this wall property: Thermal lag (TL) and Decrement Factor (DF) [7].

TL is defined by equation 3:

$$\text{eq.3} \quad TL = \vartheta_{T_{\max,ext}} - \vartheta_{T_{\max,int}} \quad [\text{h}]$$

that estimates the time that maximum temperature takes to propagate from the external surface to the internal surface of the wall.

DF is defined by equation 4:

$$\text{eq.4} \quad DF = \frac{T_{\max,int} - T_{\min,int}}{T_{\max,ext} - T_{\min,ext}} \times 100 \quad [\%]$$

that estimates the decreasing ratio of its amplitude between internal and external temperature.

Both parameters depend on thermal diffusivity, a property of each material that estimates the rate at which heat is transmitted through the same material.

Thermal diffusivity is function of the three quantities listed in table 1, according to this relation:

$$\text{eq.5:} \quad a = \frac{\lambda}{\rho \times c_p} \quad [\text{m}^2/\text{s}]$$

if also this parameter is considered, it is clear that expanded clay offers better performances (lower value) respect to the other assembling panel materials (table 3).

Table 3. Thermal diffusivity of the materials considered

Material	Thermal diffusivity [m <sup>2</sup> /s]
Concrete	0,90 E-06
Expanded polystyrene	2,5 E-06
Expanded clay	0,30 E-06

In order to optimize thermal behaviour both in the steady (U-value) and dynamic state (thermal diffusivity) of the whole panel, a new panel prototype has been designed and developed: a lightweight and thermal barrier panel, whose plan view is reported in figure 7. Thermal barrier is obtained with a layer of expanded clay (thickness 0,08 m), while the structural lightening with the expanded polystyrene (thickness 0,04 m): the first material performs heat storage capability of the panel, the second its insulating capability.

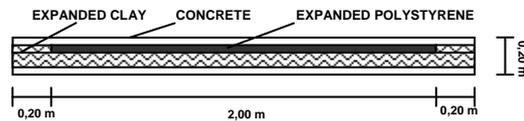


Fig 7. Plan view of lightweight and thermal barrier panel

In order to validate the U-value of the new panel it is compared the numerical value obtained by Comsol Multiphysics with the resulting value by in situ measurement carried out in the test facility [4].

From section reported in figure 8 it can be inferred that heat flux is characterized by a bi-dimensional field, because of the presence of thermal bridges produced by material discontinuity between expanded polystyrene and expanded clay. In the same figure 8 it is possible to distinguish quite clearly two zones with different heat flux values: zone A (with expanded polystyrene) and zone B (without expanded polystyrene).

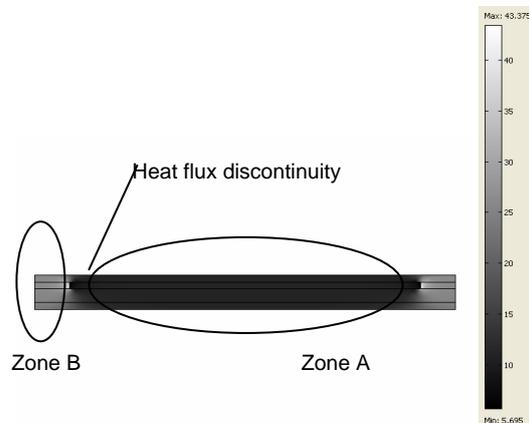


Fig 8. 2-D heat flux field for the new designed panel

Both zones are characterized by a nearly one-dimensional heat flux field, neglecting a relative small boundary zone; so this allows to measure

U-value of zone A and U-value of zone B separately [8]. The overall U-value will be obtained from the area weighted average U-values of the two zones.

For this panel the weighted U-value, calculated with Comsol Multiphysics, solving heat transfer problem with 2-D geometry, is 0,91 W/m<sup>2</sup>K: the decrement respect to the starting panel is 60,3%.

The experimental values, obtained from the test-facility above described and using Trysis01 system, are reported in figure 9 on the basis of above mentioned equation 2 (on a time basis acquisition of 7 days), applied for two zones.

Data reported in figure 9 show that U-value:

- for the zone A, tends to 0.72 W/m<sup>2</sup>K
- for the second zone B, tends to 1.48 W/m<sup>2</sup>K.

Since the ratio of two areas is 1:6, the experimental U-value for the whole panel is 0,85 W/m<sup>2</sup>K, 6,6% lower respect to the numerical value.

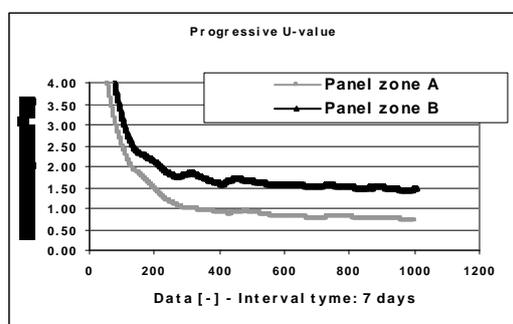


Fig 9. U-value measured data for zones A and B of the new panel

#### 4. Conclusions

In this article the development of a concrete precast panel used in an industrial building application has been analyzed in term of thermophysical performances (transmittance value, thermal lag, decrement factor). Starting from an actual precast concrete reinforced panel, some numerical process was carried out using a software simulation able to solve differential equation with the finite difference method in order to improve thermal behaviour of the panel. This process has led to design and develop a new lightweight and thermal barrier panel, able to warrant heat storage and thermal isolation, improving energetic behaviour in steady and dynamic states.

At the same time a methodology has been proposed, applicable for every component, to confirm in situ thermal properties obtained with software simulation.

The results show a very good agreement on the measurement of local panel transmittance compared to the Comsol simulations about the new panel prototype. Besides the new designed panel has improved U-value of more than 60%, as well as thermal inertia.

A further study will lead to quantify the better dynamic performance of this panel and to

express these improvements in terms of energetic saving for the building.

#### 5. Acknowledgements

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#### 6. References

1. Agrément South Africa (2002). Performance criteria: building and walling systems – Criteria for the thermal performance of buildings. October. Available: <http://www.agrement.co.za>.
2. VanGeem, M. (2006). *Achieving Sustainability with Precast Concrete*. PCI Journal, January-February.
3. Chouinard, K. et al. (2006). CMHC's New Best Practice Guide - Architectural Precast Concrete Walls. *Building Envelope Forum*, 6th Edition Online Newsletter Articles, September.
4. Sibilio S., Maffei L. and Possidente R., (2007). Environmental and energetic design of a precast concrete panel for commercial and industrial building. Proceedings *International Congress CLIMAMED 2007: energy, climate and indoor comfort in Mediterranean countries*, AICARR: Session C, pp. 311-324, Genova, Italy, September 5-7.
5. ISO 9869 (1994). *Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance*.
6. Doran S. (2000). Field investigations of the thermal performance of construction elements as built. *Building Research Establishment, BRE East Kilbride*. Glasgow, Scotland.
7. Asan H. (1998). Effects of wall's insulation thickness and position on time lag and decrement factor. *Energy and Building*, 28 (3): pp.299-305.
8. Maffei L., Possidente R., Sibilio S. (2006). In situ analysis of energetic performance for a precast concrete panel in an industrial building. Proceedings *17<sup>th</sup> Air Conditioning and Ventilation Conference 2006*: pp. 275-281, Prague, Czech Republic, May 17-19.