Changing Needs, Adaptive Buildings, Smart Cities

Volume 1

- Analytical, Experimental Research Results.
- Building Design Analytical Behaviour Presentations.
- Critical Reviews.
- Methods, Methodologies.
- Product-Oriented, Process-Oriented Design and Applications.

Edited by
Oktay URAL
Emilio PIZZI
Sergio CROCE
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The World at IAHS 2013

Participating Countries


FOREWORD

The Proceedings of 'The 39th IAHS World Congress: Changing Needs; Adaptive Buildings; Smart Cities' will introduce abundant innovative ideas with participants from many corners of the world. Against the backdrop of Milan, Italy, this Congress will present a great challenge to all of us: to evaluate our present knowledge and arrive at a new platform where new and innovative concepts are introduced. Housing Science, inherently has a dynamic nature. Innovative change in housing, against a background of economic and technological changes, is inseparable from its existence and applications. The title of the congress reflects this fact as it emphasizes the multi-disciplinary topics that have an impact on issues of Housing Science. More than two hundred manuscripts will analyse and study special issues with respect to planning, sustainability, technology, refurbishments, durability and policies. Their impact will be present in every technical session of the congress, culminating in integrated recommendations for future adaptive buildings and smart cities.

We must realize that the future of our world will depend on how we can plan and manage the potential of the world’s urban centres. We project that the megacities will support over six billion people by the year 2050. This fact will translate into complicated social and economic activities. The societal quality of life will depend on how well we will direct the renewable energy resources for consumption all the while ensuring to protect the environment. The planning and construction of the intelligent buildings will create the smart cities with their complicated infrastructures, the level and success of which will define the boundaries of the quality of life. The success of the smart cities will depend on economics, mobility, environment, culture, and governance to be sustainable.

We are honoured to be the guests of an outstanding European institution of higher learning: Politecnico di Milano – Department of Architecture, Built environment and Construction engineering (ABC). The City of Milan is one of the most historic and cultural cities of Europe. The congress participants, from numerous countries across the globe, will discover the combined values of history, culture and hospitality of Northern Italy. This will prove to be a memorable experience for each congress participant. Being in Milan, has another advantage, as the European Union (EU) is involved in multiple studies on strategies for smart cities and innovations to enhance the lives of their citizens. The key to success is to get populations involved in open innovative processes. The EU also initiated a project on energy efficient cities, Planning for Energy Efficient Cities (PLEEC), predicting difficulties in future energy provisions. There are, as cited, major tasks facing our world. We have to rise to the challenge and reach successful results.

International Association for Housing Science, IAHS, is a non-profit scientific world organization. It was founded at the University of Missouri – USA in 1972. It is enjoying forty-one years of global activities. This year, the Milan World Congress is the 39th successful global event. The Proceedings of all previous congresses are available on the webpage: <www.housingscience.org>. IAHS would like to recognize and express our appreciation to the Politecnico di Milano, and especially to Professor Emilio Pizzi, his colleagues and his extended team who made this a successful global event. We welcome you, each of you, to the 39th IAHS Congress and to Milan. We wish you an enjoyable stay, hoping you will return to your institutions not only with an abundance of new knowledge but also with an abundance of new friends.

Regards to all.

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Professor Emeritus, The International Association for Housing Science (IAHS), President, Miami, USA.

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39th International Association for Housing Science (IAHS) World Congress Executive Scientific Responsible.
The job of finalising the scientific programme of the Congress, given the number of papers submitted, intensely involved members of the international and local scientific committee who collaborated in the blind review.

It is therefore first of all necessary to express our warm thanks to the Reviewers who played a significant part in the scientific success of the Congress.

Thanks also go to the Authors who were subjected to the ‘harassment’ of the Reviewers: something not frequent in Congresses but normal practice in the most important international scientific circles.

As it was not possible, given the number of papers, to allow all Authors to make an oral presentation, the selection was based on the assessments of members of the National and International Scientific Committee, giving precedence to conclusive research results.

The other papers accepted by the Scientific Committee, of equal interest, were placed in a special and important review session to give all Authors appropriate and important visibility.

The Proceedings were therefore published in two Volumes.

In the first Volume, which includes papers admitted for oral presentation, are papers pertaining to the results of completed research and the documentation of specific and different issues related to the social and cultural specificities of the many countries present at the congress.

In the second Volume, which includes papers admitted to the review session, are papers concerning practical analyses, preliminary studies, product reviews, project presentations and state-of-the-art reports.

The third Volume, entitled ‘Nothing is Permanent’, includes, with attractive graphics, iconic reflections of Peter Schmid in partial collaboration with Gabriella Pál-Schmid with reference to each of the numerous IAHS Congresses in which he has participated. This is a kind and precious gift of Professor Schmid to participants of this Congress, to whom we express our sincere gratitude.

In editing the papers and preparing them for inclusion in the Proceedings, every effort was made to produce a faithful reflection of the Authors’ contributions based on their revised manuscripts.

In preparing the Volumes, particular attention was also paid to the publishing graphic aspects.

Another activity subject to particular attention, due to the fact that Authors of English mother tongue were by far the minority of those present, concerns the opportunity to request a limited linguistic review and for this we apologise to the Authors.

Publication of the Proceedings was made possible by the much-appreciated contribution of the Authors, but also by the behind-the-scenes effort of the Reviewers whose dedication and knowledge should be recognised and to whom we express our gratitude. The scientific level of this congress was the direct result of their respected opinions.

A salient and positive peculiarity of this Congress was the participation of Authors from as many as forty countries. It was therefore an important opportunity to meet that can only foster and broaden the possibilities of establishing scientific relations between the universities and research centres represented.

Reading the Proceedings, therefore, provides an interesting scenario on the global trends of research in the various scientific fields. And this also due to the fact that there are significant contributions for advancement in the various research fields.

One of the first interesting aspects we come across while reading the manuscripts is the infrequent use of the term ‘sustainability’ in the titles and throughout the text. This is in itself surprising as it may indicate a paucity of attention being paid to those problems concerning the correct evolution of urban planning, architecture and building design in terms of a more responsible attitude toward environmental issues and the life of future generations. Indeed, if we get to the heart of the matter, we cannot help but notice how raising awareness about sustainability has become a common – albeit unavowed – narrative, which has in turn become part and parcel of those rules governing the art of research in the industry, while tampering with any planning practices in the process.
The season of meaningless self-celebrations of sustainability, which may still be found in glossy architecture magazines, is seemingly over. A second aspect to highlight is the congress topic dedicated to Urban and City Planning. The World Health Organization of the UNDP highlights the fact that 40% of the world population currently lives in a city and that this percentage will rise to 60% by 2030. In particular, the UNDP (United Nations Development Programme) anticipates that in 2015, in the countries with highest HDI (Human Development Index), the urban population will reach 78.5% of the entire population, with an annual increase of 1.7%. There are many problems related to this global phenomenon. In particular, they require new approaches in growth, policies in order to control so-called Urban Sprawl and Ecological Footprint. In this regard, the issues that figure predominantly are those aimed to safeguard the urban heritage and the urban transformation, to rehabilitate and manage informal settlements as well as reclaim degraded and crime-ridden suburbs plagued by severe social hardship. Equally interesting are those projects/essays highlighting the virtuous changes that have been gradually applied to the urban structure in quite diverse environments. Fewer measures, however, have been taken to curb urban build up in an effort to restrain urban sprawl. Similarly, little has been done to reduce overheating in urban environments as a result of the UHI (Urban Heat Island) phenomenon. In particular, altering the conditions of thermal comfort in urban environments has significant social and health repercussions, which call for greater attention. As can be seen, the topic of Building Design, as one would expect, has the highest number of contributions. Of course many papers were focused on the topic of Nearly Zero Energy Buildings and recourse to renewable energy sources, also in relation to obligations imposed in this regard by the European Community. The topic of forecast modelling of the environmental conditions of buildings for the development of climate sensitive buildings, such as those that characterised the vernacular architecture of the past, appears to have been investigated less. New materials, technologies and the availability of sophisticated simulation models in fact already allow for highly innovative design approaches with respect to the current architectural and technological scenario. Another aspect investigated in detail, in papers characterised by an in-depth engineering approach, concerns seismic events, the corresponding risk analyses, measures to counter the effects and evacuation and reconstruction interventions. Much attention was also placed on a topic currently scarcely studied such as that of housing configuration typology, where approaches related to the specific culture and different socio-economic situations are compared in a very different way. Examining the interventions, also the broad topic of Refurbishment-Rehabilitation-Restoration has a large number of papers that develop historical insights, decision support methodologies and application examples, many of which are again related to energy issues. Some of these use the analysis of technological and architectural models that characterise certain areas (geo-cluster characterization) for the development of large-scale refurbishment strategies. Others concern analyses oriented towards recognition of the thermal behaviour of buildings, necessary to define the interventions. Naturally, many papers focus on intervention techniques also via experimental approaches typical of restoration. In third place is the topic of Innovation-Building technology-Construction. Many are the papers dealing with new materials and systems such as solar screens, vacuum insulation, phase transition materials, photovoltaic panels, glass, textile structure, reflective layers and recycled materials. The energy sector naturally attracts most interest. On the construction industry front on which the topic is developed, papers range from the presentation of quality control methodologies, risk analyses, technological optimisation systems and new experimental methods for material behaviour analysis. Facility management, building condition assessment, construction supply chain, adaptive and predictive analysis, environmental assessment and waste in construction are some of the other topics addressed. Congress topics dedicated to Legal, Economic and Financial Policies and Building Life Cycle on the other hand had fewer interventions than the other topics, but all still very up-to-date and interesting. Regarding the issue of Building Life cycle papers are concentrated in particular on methodological aspects related to risk assessment, service life prediction and maintenance. In conclusion, as a whole the papers present a variegated and selected panorama of approaches, methods, techniques, tools, systems and technologies aimed at improving knowledge of the topics investigated. Certainly their reading will allow a better understanding of the problems that characterize the urban and architecture sector in the various countries and of the issues on which to focus the development of positive collaboration and interaction between the members of such a vast, multicultural and interesting scientific forum.

Witness by my hand.

Professor Sergio CROCE
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39th International Association for Housing Science (IAHS) World Congress Executive Scientific Responsible.

Endnotes
The Ecological Footprint measures the amount of biologically productive land and sea area an individual, a region, all of humanity, or a human activity requires to produce the resources it consumes and absorb the waste it generates, and compares this measurement to how much land and sea area is available. More information: <http://www.footprintnetwork.org/en/index.php/GFN/>. 
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BUILDING DESIGN
PERFORMANCE ANALYSIS OF INNOVATIVE VACUUM INSULATION PANEL

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Keywords: Advanced Materials; Building Technologies; Insulating Performance; Retrofit; Thermal Conductivity.

Abstract
Thermal insulation has become one of the central themes in energy behaviour improvement. The use of insulating materials, from the thermal and hygrothermal aspect, allows the reduction of the heat transfer in each of the technical elements increasing their thermal inertia. Even if the research has led to the use of innovative materials with high values of thermal insulation, one of the main problems, which is difficult to resolve, is the thickness of the building envelope to reach levels of transmittance that can allow considerable savings of energy and CO₂ emissions. With this objective the VIP (Vacuum Insulation Panel) technology in building applications is an innovative solution to obtain very low values of thermal conductivity, with reduced thicknesses. This latter aspect is even more relevant in the energy retrofit of constructions, where the request for an adjustment to higher levels of energy efficiency requires an addition of insulating material layers. In particular, the VIP consist of an open cell structure, made with different kinds of materials, for the realization of an evacuated chamber and an envelope to maintain the very low internal pressure (10⁻⁵⁻¹⁻³ mBar).

The Dipartimento di Architettura of the Università of Palermo has developed a research study on VIP applications in buildings. The study has been developed by different steps:
- Study of the state of the art, with particular reference to commercially available systems and institutional systems.
- Evaluation of the critical issues during the production and installation phases;
- Reviews of the thermal and mechanical performances;
- Research for new materials adaptable to the VIP technology.

The paper will show some aspects of the research such as the benefits of each solution through a cost-benefit analysis that can provide useful information for an appropriate choice aimed at reducing costs and at improving energy performance.

1. Vacuum as Thermo-Acoustic Insulation
Vacuum is a space in which there is no matter or in which the pressure is lower than the atmospheric pressure, and not necessarily null. The lowest pressures currently achievable in laboratory are about 10⁻¹³ Pa (through special ionization vacuum gauges tested as early as the Second World War).

Thermal conductivity of a material depends on its density and on collisions between the gas particles. It increases with the number of particles per unit volume, for this reason gas blocks heat very well: the conductivity of dehydrated air, argon and krypton are respectively 0.025 W/m²K, 0.01772 W/m²K and 0.00949 W/m²K.

The vacuum system is the best way to reach a low thermal conductivity because it eliminates heat transfer by conduction and convection, allowing only the radiation component. Moreover, vacuum offers a further advantage because it does not depend on the cavity thickness, but it has a constant thermal conductivity.

Vacuum technologies have been developed gradually thanks to the advances in industry and research. Experimentations are numerous and cover a wide range of application: metallurgical, food and aerospace industries, systems for controlled nuclear fusion, microelectronics, surface science, etc.

Also for buildings one of the most recent challenges is exploiting the characteristics of vacuum for thermo-acoustic insulation.

VIP technology offers an interesting evolution in insulation and allows for the substitution of conventional insulation materials with an increased level of insulation (from 5 to 10 times greater) as well as a reduction in the space required.

2. VIP (Vacuum Insulation Panels)
The Vacuum Insulation Panels, widely known as ‘VIP’, use the properties of the insulating vacuum in order to obtain high thermal performance using small thicknesses.

To eliminate heat flow by gas conduction, it is necessary to evacuate the gap at pressures of the order of 10⁻¹⁻¹⁻³ mbar. Instead, to reduce heat transfer by solid conduction, i.e. the one that occurs between surfaces delimiting the evacuated gap, it is necessary to minimize the number of points of contact between the above mentioned surfaces, limiting thermal bridges.

VIP are used in building either as opaque or transparent structures. Regarding the former, the low conductivity of the vacuum is exploited through sandwich panels consisting of a solid internal evacuated block called ‘core’.

In the case of transparent surfaces, instead, an important VIP technology innovation is VIG (Vacuum Insulation Glasses), which allow the creation of glass walls with low transmittance (of the order of 0.5 W/m²K), through a vacuum chamber a fraction of a millimetre thick.

3. Opaque Panels
VIP technology allows obtaining opaque insulating panels of a few millimetres (the most common thicknesses are between 10 and 40 mm) with a low transmittance value (ranging from 0.12 to 0.50 W/m²K).

Opaque VIP include a solid inner core, surrounded by a permeable felt that provide mechanical stability and protection for the core. The package thus composed is in turn enclosed by an outer covering, usually consisting of a plastic or aluminium envelope, which protects it and makes the core impermeable to air and water and at a constant pressure considerably lower than the atmospheric pressure (between 0.1 and 20 mbar).

3.1. VIP Core
To ensure vacuum condition and low pressure within the panel, it is necessary to realize the core with a porous material and with an open structure, from which the air contained inside the pores can be evacuated. These materials must comply with a few requirements: very small pore diameter, open cell structure, low water content, impermeability to infrared radiation and resistance to a very low pressure of mbar.

As regards to the heat transmission inside the panels, the convective contribution can be neglected by using materials with a pore size such as to break the convection inside the cavity. For this reason, micro or nano-structured materials are preferable for the realization of the core materials, in which it is possible to achieve the necessary vacuum condition for a low thermal conductivity with a small pore size.

The heat contribution by solid conduction depends not only on the choice of a material with
low thermal conductivity, but also on the minimization of the points of contact between the surfaces delimiting the evacuated gap. Moreover the water content of the material affects the thermal conductivity of the core: the conductivity increases with the increase of water content. The heat transmission by radiation can also be opposed by covering the walls of the inner container with reflective materials, able to limit the permeability to infrared radiation.

The last critical parameter is the strength of its microstructure, which has to support the low pressures to which it is subjected in order to ensure the vacuum between particles. The pressure inside of a VIP is a few mbar, consequently, the pressure load on the panel is close to 1 bar, so the core material must be stable enough so that pores do not collapse when the air is removed [1].

Currently the commercially available, most used materials for the realization of the core are glass fibres, fumed silica and polyurethane foam [3]. As a result of studies carried out on these materials and the technical characteristics of the different VIP panels available in the market, the most effective solution in terms of thermal performance and durability is obtained with fumed silica powder. This material is considered the best both for the small pore size and for the very low thermal conductivity $\lambda$.

Moreover, the vacuum insulation panels in fumed silica, unlike other products, have a higher durability, ranging from 30 to 50 years, compared with durability of polyurethane VIP (15 years) and of glass wool VIP (only 5 years). VIP may be of different sizes, thicknesses and geometries and may achieve different levels of transmittance. Considering a panel with a 1000x600x20 millimetres fumed silica core, the transmittance value $U$ is equal to 0.22 W/m$^2$$^\circ$K.

### 3.2. The Envelope

The most critical component of a vacuum insulation panel is the outer envelope, responsible for maintaining the vacuum inside the panel. Indeed it must satisfy important requirements in the long term, such as: low oxygen permeation, low permeation to water vapour, high mechanical strength, low thermal conductivity and compatibility with other construction materials (adhesives, foams, chalk). The VIP envelopes are made with polymer film laminates and/or aluminium (thickness ranging from 7 to 12 $\mu$m) able to ensure the required characteristics of the VIP panel. Several layers of films can be used by rolling or welded metal sheets. Sometimes it is also necessary to insert a special device able to absorb the gases accumulated over time for permeation and degassing and which may considerably deteriorate the vacuum level decreasing panel performance. This device able to absorb gas is called ‘getter’ and it is dimensioned in relation to the characteristics of the panel, to its working conditions and to the expected duration. However, the use of fumed silica powder as core material increases the tolerable internal pressure by more than an order of magnitude. In this way fumed silica can maintain low thermal conductivity to a much lower value threshold than other materials, even for growing values of the pressure.

![Figure 1. Thermal conductivity of air as a function of pore diameter [2].](image1)

3.3. Discussion: Limits of Applicability

One of the greatest difficulties related to the construction and use of vacuum panel technology is the maintenance of the performance and the vacuum condition over time. Indeed the pressure inside the core is subject to increase, with consequent deterioration of the vacuum in the panel due to the diffusion of gases present in the environment through the outer envelope which surrounds the core (gas permeation), and subsequently the gas release from part of the outer film and of the filling material (thermal desorption). Even during the processing and the sealing steps, gas residues could get trapped inside, leading to a more rapid deterioration of the panel thermo-insulation characteristics. In particular, the envelope sealing is responsible for the oxygen and water vapour permeation through the sealing edges. The permeation is proportional to the joint length, to the thickness and to the permeability of the sealant material.

![Figure 2. VIP Components.](image2)

![Figure 3. VIP with fumed silica core wrapped in laminated aluminium foil.](image3)
To limit the gas permeation inside the panel, special materials are used, obtained by the rolling of various polymeric layers, sometimes also metallic or inclusive of an aluminium continuous sheet, able to perform the function of the gas-barrier almost absolute [4]. Another problem which affects the VIP thermal behaviour regards the thermal bridge between core and envelope, generated by the high thermal conductivity of dense materials used as the barrier (often aluminium) compared to the porous material of the core.

4. Transparent Panels
The technology of VIG panels (Vacuum Insulated Glass) derives from the already widely diffused technology of insulating glass. The introduction of insulating glass has reduced heat transmission by convection and conduction in transparent panels up to current solutions with triple glazing and Krypton gas, able to reach transmittance values comparable, or even lower, to those of common opaque insulating panels. Some manufacturers have implemented a further evolution of the concept of insulating glass, aiming to achieve better results in terms of thermal insulation. Thanks to the realization of the vacuum gap in the glass panel it is possible to eliminate the heat transfer by conduction and convection between the glass panes. The thermal benefit is not dependent on the cavity thickness, allowing to leave a few tenths of millimetre between a pane and the other.

Table 1: Comparison of transmittances obtained with different types of glass.

<table>
<thead>
<tr>
<th>GLASS TYPE</th>
<th>Single glass (6mm)</th>
<th>Insulating glass with air (6-16-6 mm)</th>
<th>Insulating glass with argon (6-16-6mm)</th>
<th>Insulating glass with krypton (6-16-6 mm)</th>
<th>VIG (0.00133 Pa) (3-0.2-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U (W/mK)</td>
<td>5.7</td>
<td>2.8</td>
<td>2.5</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The system can be composed with different solutions that include two or three glass panes (hardened, tempered, laminated with or without low-emissivity treatment) sealed at the edges with glass-plates, metal foils or other materials based on organic-inorganic polymer. The air is extracted from the cavity by a valve applied on one of the outer panes.

4.1. Discussion: Limits of Applicability
However, the benefits of VIG panels for the building envelope insulation are also accompanied by different problems concerning their design and implementation. They require the integration of different aspects such as the choice of sealing material, that has to be airtight but cannot reach too high melting temperatures in order to avoid damage to the low-emissivity treatment of the inner part of the glass pane. To obtain a good seal it is necessary to have loss rates less than or equal to 10-12 mbar l/s. Moreover, the realization of the vacuum determines high pressures (10 Pa) which require the insertion of the mesh of spacers with a consequent decrease in the insulating capacity. The pitch of the mesh must conciliate the thermal bridges which are determined by the stresses that the sheets must tolerate and also the diameter of each spacer must be small, in order to reduce the visual impact, and also resistant to the pressure stress generated between the glass panes [5].

On this issue different experiments are currently in progress, these are verifying the best value in terms of performance and cost. Currently these limits of applicability have produced the negative effect of a low panels diffusion on the European market.

5. Conclusion. Cost-Benefit Ratio
Economic evaluations to verify the application convenience have been developed as regards the two vacuum panels analysed (opaque and transparent). In particular the results, for the transparent panels, have been not included because the obtainable data was still referred a too restricted application field. Instead, in opaque panels applications, the different energy savings measures have been compared by economic aspects. The mathematics financial methods have been used to evaluate the convenience of an initial investment with the future economic saving that is generated by the system itself during its work. The analysis was carried out through the elaboration of the thermal load for an office work. The analysis was carried out through the elaboration of the thermal load for an office considering: in summer an external temperature of 35 °C with an internal temperature of 26 °C, in winter an external temperature of 5 °C with an internal temperature of 20 °C. Finals simulations have shown the VIP application is more convenient, after a greater number of years in comparison with conventional thermal insulation panels (EPS). This can be deduced from the results, in particular the reduction of the annual energy requirements and the consequent economic saving.

Table 2: Comparison of the general assessment of costs.

<table>
<thead>
<tr>
<th></th>
<th>Traditional structure</th>
<th>EPS</th>
<th>VIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation cost (€/m²)</td>
<td>0,00</td>
<td>14,00</td>
<td>75,00</td>
</tr>
<tr>
<td>Initial investment</td>
<td>0,00</td>
<td>181,44</td>
<td>972,00</td>
</tr>
<tr>
<td>Annual energy requirements (KWh)</td>
<td>1602,13</td>
<td>995,91</td>
<td>752,43</td>
</tr>
</tbody>
</table>
In order to verify the actual cost/benefit analysis, the pay-back time and the net present value (NPV) have been used. The first financial indicator showed that the thermal insulation in EPS generates profits in a shorter time (1 year and 1 month) compared with vacuum insulation panels (4 years and 4 months), because the VIP system request an high initial investment.

The VIP technology application produced an higher annual economic saving, so the NPV (Net Present Value) has been used to calculate the saving in a specific number of years used as a reference.

Through this financial method, it was possible to detect the preference of the investment with EPS insulation until the fourteenth year of operation, over this period the use of VIP system is more convenient.

Figure 5. Graphical representation of financial indicators.

Notes
(1) In a region of space devoid of matter collisions between particles cannot occur. Actually, the vacuum would be a perfect insulator if it did not let pass another form of thermal energy, namely the infrared radiation transmitted by all the warm bodies.

(2) When the ‘mean free path’, which is the average distance travelled by a particle between two successive collisions, reaches values that are in the order of magnitude higher than the one of the pores, the conductivity of the gas is null.

(3) The system Spacia consists of two sheets separated by a series of support pillars (micro spacers) with a thickness of 0.2 mm and 0.5 mm in diameter in order to keep uniform the empty space. The pillars are distant 20 mm from each other. The edge of the glass is sealed with a glass weld joint compatible with the expansion coefficient of the float glass.

List of References
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