INNOVATIVE FIBRE-CEMENT SOLUTIONS FOR SMART-ECO BUILDINGS OF 2020-30

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ABSTRACT

The construction sector is facing extraordinary challenges, as in 2020 all new buildings will have to reach the "nearly zero energy" standard. This paper presents the main findings of the Smart-ECO research project, funded by the European Commission to define a vision of sustainable buildings in twenty years time and the innovations required to implement it. The paper will also introduce the practical results of three different research works about components for energy-efficient buildings, showing how fibre-cement products can be fully integrated in innovative solutions. A demonstrative building in Italy, designed and realised as a part of a research project, finally shows some of these innovative components applied in practice.

KEYWORDS:

Fibre-cement in buildings; energy-efficient architecture; technological innovation; phase change materials; innovative insulation.

INTRODUCTION

In order to reach the 20-20-20 goal in 2020, the European Commission attributes strategic importance to energy efficiency measures in the field of construction (European Commission, 2007). The reason for this is the huge impact of buildings on energy consumption and carbon emissions, estimated respectively at 40% and 20% of the total (European Commission, 2009). On the other hand, design strategies and technologies to improve dramatically the energy efficiency of buildings are already available: this is why the recast of Directive 2002/91 on energy efficiency of buildings (EPBD) sets the target of "nearly zero energy standard" for all buildings constructed after 2020, with the target being anticipated at 2018 for public buildings (European Commission, 2008). To reach this target, buildings will have to minimise their energy needs and produce most of their energy from on-site renewable sources.

The European research project Smart-ECO (*Sustainable Smart Eco-Buildings in the EU*), closed in April 2010, was a part of the FP6 Eco-buildings topic. Its main goals were:

- defining a vision of European sustainable buildings in 2020-2030;
- identifying the innovations (technologies and process) required to implement the vision;
- evaluating the most promising innovations;

and disseminating the results among the operators of the construction sector in view of the 2020 energy efficiency targets, while not limiting the research field to this topic.

Smart-ECO relied on a wide group of stakeholders to build a consensus-based vision and to identify the relevant innovations. Stakeholders were involved in the research project through questionnaires and specific workshops held during the periodic project meetings.

The research group was composed by 14 partners and was coordinated by BMG Gävle (Sweden) [1].

This paper will present the main findings of the research, describing briefly what should be the characteristics of a Smart-ECO building in 2020-30, and the innovations required to achieve this standard. Among the very large number of innovations contributing to the Smart-ECO vision, three examples involving the use of fibre-cement products will be presented. Finally, this paper will describe an experimental building located in Lodi, Italy, presenting very high energy efficiency (in winter and summer) and the use of innovative components that qualify it as a Smart-ECO building.

SMART-ECO BUILDINGS IN 2020-30

Vision

A very important part of the Smart-ECO research project (workpackage 2) was the definition of a "vision" of buildings in 2020-2030, shared by the research group and the stakeholders alike. Along with the recent ISO 15392:2008 standard about the definition of sustainability applied to buildings, the research considered other important aspects defining the state of the art about sustainability, such as CIB's Agenda 21 (CIB, 1999), the various national legislations, certification and evaluation tools, etc.

According to the resulting vision, a Smart-ECO building in twenty years should:

1. be designed from a lifecycle point of view;
2. be constructed with limited resources and minimised energy consumption and waste production;
3. have minimised operational complexity while allowing easy monitoring of technical and environmental performances;
4. be adaptable to changes in capacity, type of users and performance requirements;
5. include local issues in all aspects of design, construction, use and dismantling;
6. facilitate ease of dismantling – reuse, recycle, restore.

As anticipated, the recast of the Directive on energy performance of buildings, which is currently in its final stages, is defining pretty clearly the requirements on energy efficiency and carbon emissions from 2018 on. Other aspects are not yet defined by regulations or best practices, but were deemed significant for the evolution of buildings (and architecture) in the next twenty years. Among them are the following.

1. Mitigation and adaptation for climate change: *mitigation* is tackling the causes of climate change through reduction of greenhouse gas emissions; *adaptation* is adjusting to the physical impacts of climate change (increased temperature, extreme climatic events, etc.).
2. Adaptation to new forms of energy: buildings constructed today will very probably be still in use when fossil fuels will be no longer available and should be ready to be retrofitted for other forms of energy supply (including renewable solar energy).
3. Integration of buildings in the energy networks: energy efficiency in buildings needs to be embedded in considerations of energy efficiency on an urban scale. The challenge for the future is the integration of centralised and de-centralised sources of energy, balancing demand and supply (which is intermittent due to the nature of renewable sources) into the so-called "*smart grids*".
4. Reducing depletion of resources: increasing scarcity and the consumption of fertile land and natural resources are a significant global problem.
5. Adaptable and flexible design for future needs: changes characterizing our society include an ageing population, urban migration, our lifestyle and work. These often make traditional building approaches obsolete. A design based on adaptability and flexibility concepts makes it possible to continue using the building even if needs have changed: this is the "*loose fit, long life*" concept.

While some of these issues may look commonsense or obvious, the real challenge for the European Commission is to have these concepts transferred to the market, making them current practice for decision-makers, designers, clients, construction companies, etc.

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[1] Partners of the research project are BMG Gävle (S), CSTB (F), Tallinn University of Technology (EST), Servitec (I), TNO (NL), Sintef (N), Fachhochschule Südwestfalen (D), Endoenergy (UK), Politecnico di Milano (I), Hywel Davies Consultancy (UK), Mace (UK) and CIB (NL).

Innovation

The goal of the research task about innovations (workpackage 3, led by Mace Ltd. with the contribution of Politecnico di Milano) was to search the construction market and the available best practices for solutions that would help implement the vision. These innovations, referred to new construction, refurbishment, or both, are typically already experimented or under development, and can be expected to hit to the market in the next few years. This pragmatic approach was chosen because the construction sector has typically long delays before an innovation is widely accepted: promotion and dissemination of these innovations will be performed by the European Commission in the coming years.

Innovations were grouped in topics ranging from design process to management, financing and other aspects of the building's life cycle. The order of the list below, presenting only the main topics that were investigated[2], reflects the conceptual importance of reducing the energy need of the building (both in winter and summer) before using renewable sources to meet it, or before considering quality of materials and other issues.

A. Whole building design (design knowledge, efficient use of existing buildings, land use, materials and waste, water conservation and storage, etc.).
B. Energy saving
    a. heating and cooling (innovative thermal insulation, innovative glazing, thermal storage, natural ventilation, control systems, etc.).
    b. lighting (natural lighting and shading, artificial lighting, etc.).
C. Energy generation and distribution from renewable sources (building, non-building, integrated generation, etc.).
D. Building construction and operation (material sourcing and manufacturing, site assembly and logistics, demolition reuse & recycling, etc.).
E. Policies (energy regulations, etc.).
F. Communication (dissemination, exemplary buildings, etc.).
G. Finance and incentives (loans, tax reduction schemes, monitoring of emissions, etc.).

Taken in isolation, the single innovations can be more or less relevant to the implementation of Smart-ECO buildings: it is quite evident that effective results can be obtained only applying *sets* of coordinated innovations, as there is no one-fit-all solution.

Whatever the set of innovations (depending on climate, type of construction, local tradition, etc.), it is fundamental to adopt an *integrated design process* considering all the phases of the building's life cycle, and balancing effectively the different disciplines involved in the project. In other words, a *holistic approach* to design is indispensable to obtain a Smart-ECO building, independently of how effective a single technology is.

MULTI-FUNCTIONAL PANEL FOR VENTILATED, INSULATED VERTICAL ENVELOPES

According to the outcomes of the Smart-ECO research project, some of the main issues for the construction sector in the next few years will be the integration of thick layers of thermal insulation in walls of reasonable dimensions, the improvement of the related construction process and the possibility of delivering "aesthetic flexibility" to designers through the use of different cladding materials. These considerations prompted a research work to design an innovative component for heavily insulated rainscreen cladding allowing to install, in one time, the insulation and the substructure for the external finishing.

Starting from an existing system for roofs (Isotec, by Brianza Plastica, composed by a metallic profile added to a panel of polyurethane encased by an embossed aluminium cover), the idea was to try to use it in vertical position, for façades. The goal was to set the best dimension and thickness of the panel, to customize it to different façade claddings and fit it to the typical joints (corner, windows etc).

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[2] A more detailed list can be found on the website www.smart-eco.eu.

The result of this research is an innovative product, one of the first to be specifically designed for low energy buildings on the Italian market. Its U-value is 0.22 W/m^{2}K (120 mm thickness) and it can bear cladding materials as heavy as 100 kg/m^2. It is lightweight and quick to install (and consequently cheaper on the side of building construction management), adaptable to different cladding materials (fibre-cement boards, terracotta tiles, rendered panels, etc.), easily recyclable and maintainable, resistant and durable.

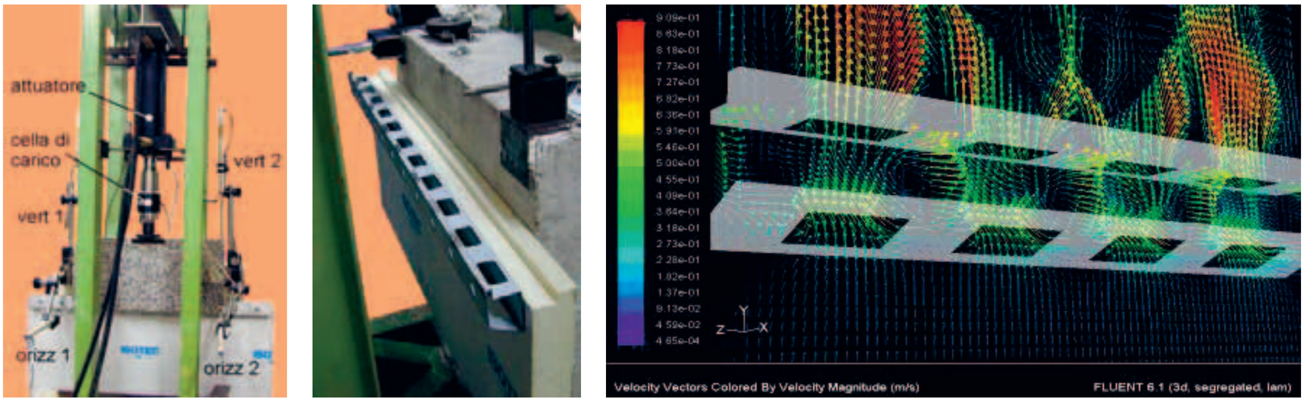

Figure 1 – Optimized profile: structural and CFD tests (to optimize dimension and distance between holes).

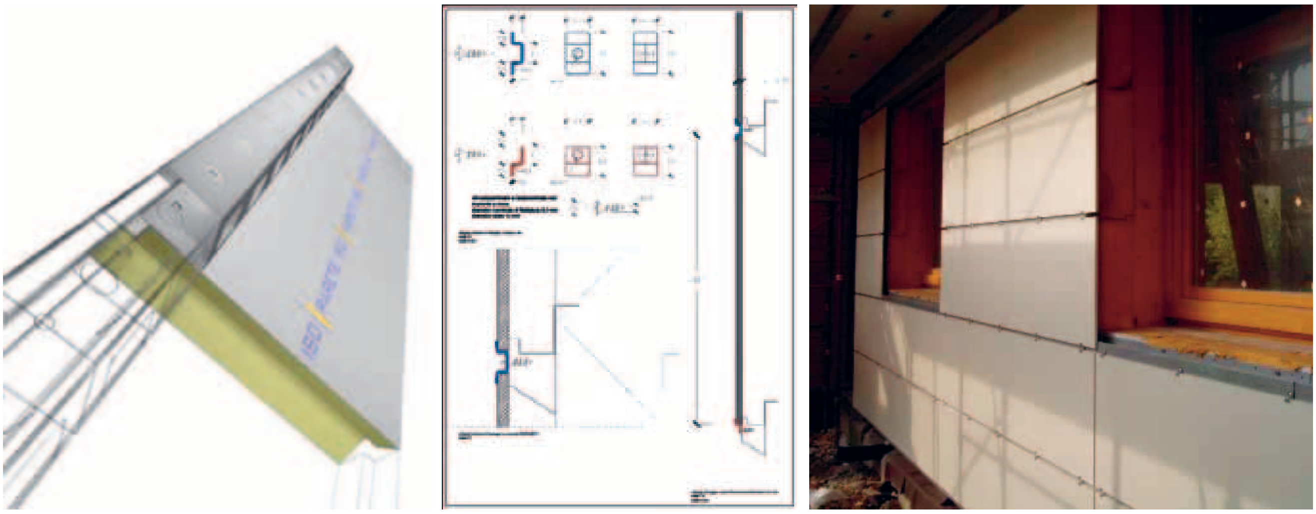

Figure 2 – The multi-functional panel for ventilated, insulated vertical envelopes and its application on site.

THE INTEGRATION OF “ARTIFICIAL THERMAL MASS” IN COMPOSITE INTERNAL LINING SOLUTIONS

Product and system innovation

Another important topic that emerged from the Smart-ECO analyses was the integration of thermal storage capacity in buildings. This issue has growing importance with the increasing use of passive devices to control indoor comfort and reduce energy consumption in building; nonetheless, very often the “thermal flywheel” effect is obtained through heavyweight components, such as concrete floors, that while being able to store and slowly release energy, also add weight to the building. Building upon the results of the former European research project C-TIDE (Imperadori et al., 2006), a recent research work focussed on the possibility of integrating phase change materials (PCM) in lightweight internal components. This work was developed during a PhD programme aiming at the enlargement of the applicative frontiers of fibre-cement and wood-cement products.

The general result was attainable through two different approaches: on one side, innovation in improving already existing products (above all concerning energetic - environmental features); on the other side, the design of components with the purpose of improving internal comfort conditions by functional combination and stratification of different materials (with different specific properties).

The first hypothesis has been followed in a theoretical way, with reference to the integration, in the mixture of composites, of titanium dioxide microcapsules or paraffin PCM; the experience was dismissed due to impossibility to fabricate and test the innovative products and then to do in situ measurements in an empiric way. On the contrary, the development of a preassembled element for floors, ceilings or walls, essentially composed of a wood-cement board as structural base, a panel of PCM for artificial thermal inertia and a finishing layer, was the core of the research.

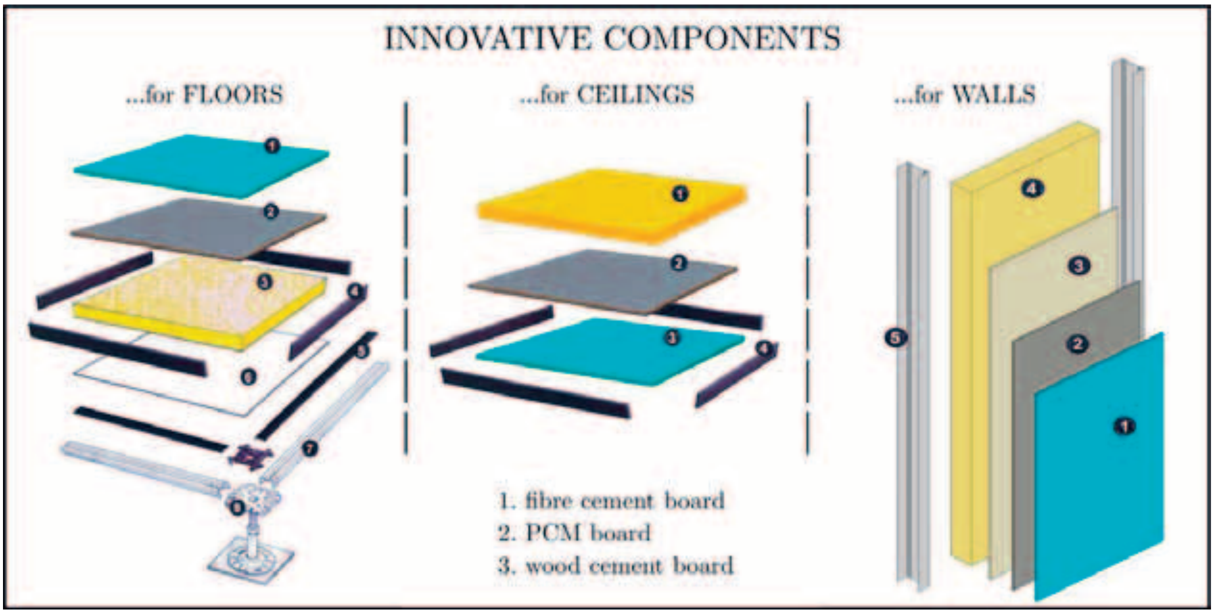

Figure 3 – Preliminary concept of the innovative preassembled elements.

The study of the possible solutions, and their effects on the comfort conditions in a tertiary building, was developed through mathematical and computational modelling and simulation.

Mathematical models

A mathematical architecture was built to develop a thermal dynamic simulation with the method of finite differences through the use of the computational software Mathcad. This preliminary simulative process allows to estimate and evaluate, in a qualitative way, the efficacy of the proposed solution, measured with the regulation of internal comfort conditions (control of operative temperatures).

Considering the main variables (in terms of influence of the comfort conditions) as orientation, location (external temperature and irradiation), geometrical and dimensional features of the office and of the glazing, quantity of PCM, total internal loads and ventilation, some considerations about the utility of application of the stratified component were extracted. Once the contribute of the components to the improvement of internal comfort conditions had been understood, a more refined mathematical model, that would minimise approximations, was developed.

A more refined mathematical model, considering an exhaustive room under specific conditions as near as possible to real conditions, was elaborated with a more adequate simulation platform (EnergyPlus v2.2.0).

The simulative process combined a complete set of detailed conditions. The possibility to integrate precise boundary conditions, playing a strong rule on final results, with climatic weather data including all the main characteristic factors (temperature, irradiation, humidity, pressure, wind, etc.) was the starting point for the improvement of the preliminary model.

Different schedules for the control of supplementary features, that can influence the performances of the components and of the entire building, were added to the preliminary model; in particular shading systems, occupancy period, total internal loads (people, lighting and equipments) and different thermal zones. Through the results extracted from the model, parameters such as the geographic location, position of the test room in the building, quality of PCM (eutectic salts or paraffin), influence due to the application of composite materials (fibre-cement and wood-cement), and efficacy of each component were evaluated.

Through the evaluation of the operative temperatures achieved inside the offices and their analysis with normative instruments, it was possible to measure the influence of each parameter on the effectiveness of the stratified components.

Once the weight/influence of variables was established, a final table for the optimization of the components was organized, so as to create appropriate guidelines for designers.

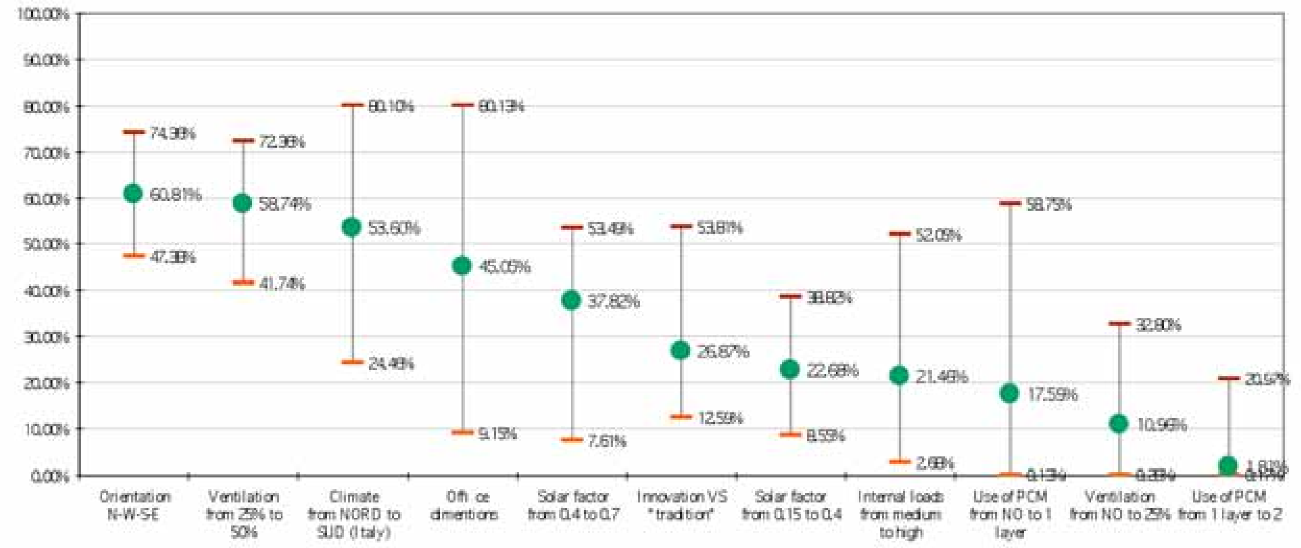

Figure 4 – Key-action influence of different parameters (PPd weighted).

Guidelines for integration of phase change materials in stratified components with fibre-cement boards

The final result of the research work, obtained through a simulative process, was resumed in a recommendation for the optimized use of the stratified preassembled solution. The idea to compress all the data in only one table derives from the will to create a user-friendly design instrument that could help designers in the application of the designed components. The efficacy of the components can be immediately understood thanks to a simplified presentation of the results. These can also be studied in a more precise way through the numeric data following the synthetic final table.

The list was organized with a flowing tree structure, essentially derived from the analyses of the incidence (and weight) of each parameter involved in the calculation. The interrogation proceeds with a series of multiple choices and the professional is driven toward the easy check of the efficacy of the components in respect to comfort conditions (EN 15251); in the case of success, also the best components solution is suggested. The guidelines, and in general the methodology applied, could be enlarged through the insertion and control of other parameters, the creation of a wider database and the development of a small software managing the information requested.

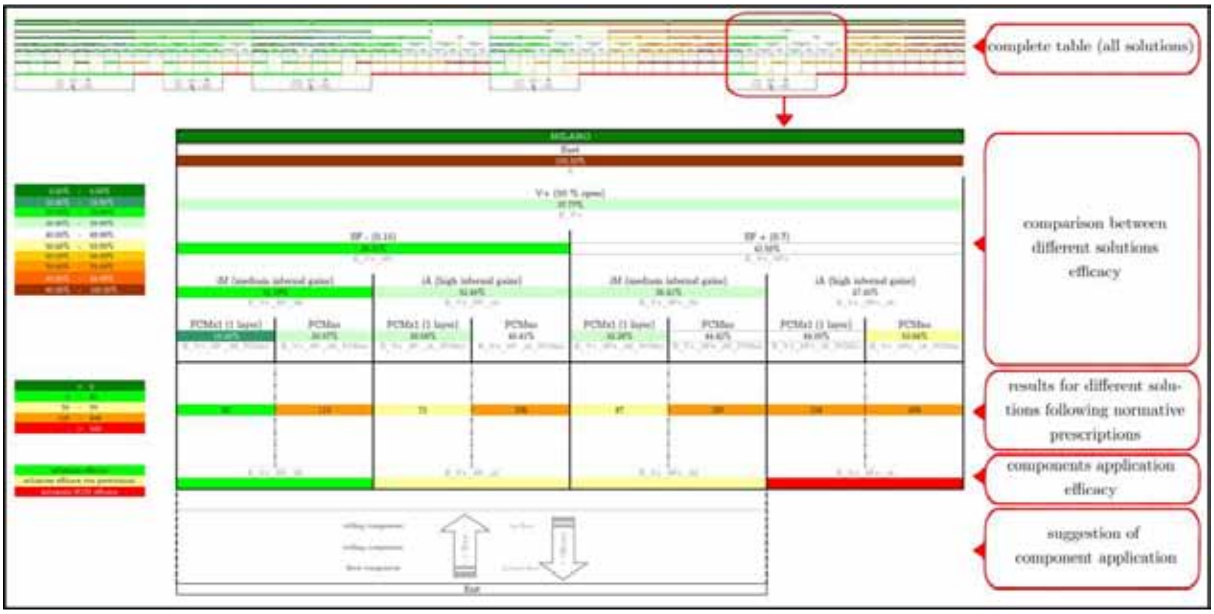

Figure 5 – Example of recommendation for the optimized use of the stratified preassembled solution.

The study on the use of fibre reinforced materials applied in the innovative components, according with the research goal, demonstrates the efficacy of fibre-cement boards compared to other traditional materials applied as finishing layer. The simulations, indicated as “Innovation vs. tradition” in Figure 4, show the influence of the parameter “fibre-cement” in the global behaviour of the innovative components. The weight of the finishing materials was evaluated keeping all the other materials of the technical components (building) and those of the innovative ones (innovative components) fixed.

For wall and false ceiling elements, the innovative solution was compared with a traditional one based on plasterboard, while for the floor the comparison was conducted on different finishing materials (linoleum, wood, etc.).

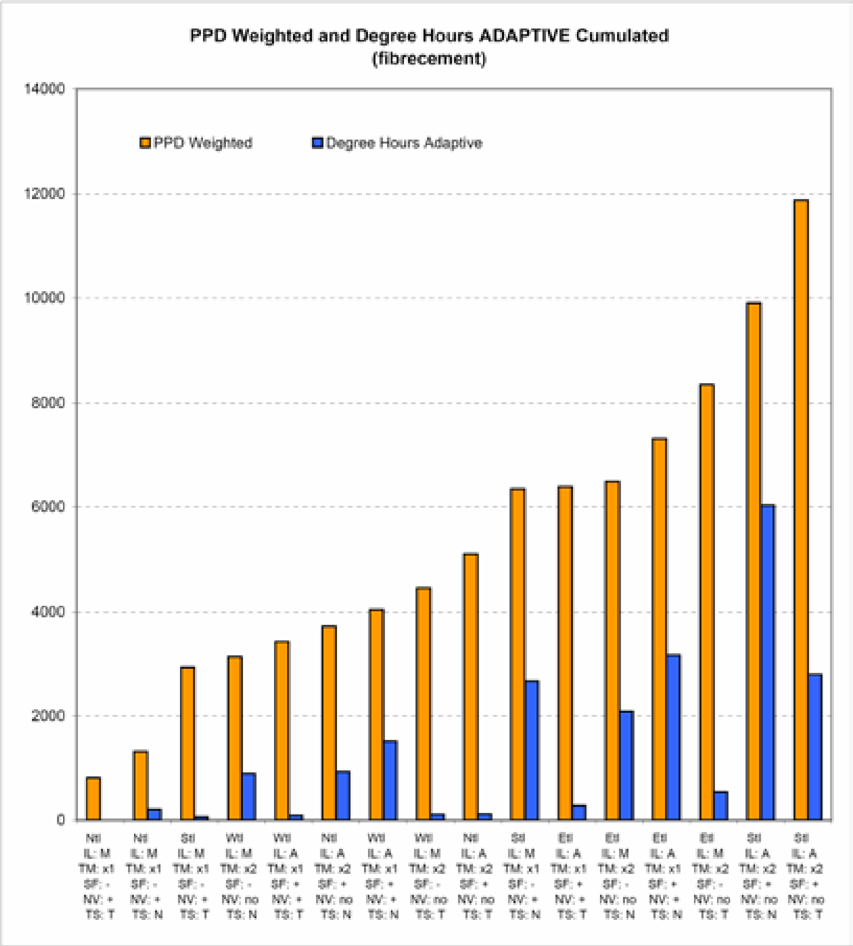

Figure 6 – Influence of fibre-cement finishing on performances of components: results of the simulation comparing components finished with fibre-cement (N) and with standard materials (T).

Fibre-cement, applied as finishing material, plays a strong role in the efficacy of the studied solutions: it combines the technical and mechanical characteristics (resistance, maintainability, etc.) with physical features (conductivity, thermal behaviour, etc) that optimise the energetic - environmental behaviour.

CASE STUDY: ENERGY-EFFICIENT BUILDING FOR A CHARITY IN LODI, ITALY

This experimental building located in Lodi (Italy) is the outcome of a research project initiated and carried out by the team led by the late professor Ettore Zambelli. The aim of the work was to design and build a suitable model for very energy-efficient residential buildings in Northern Italy, where, although the climate is temperate, extremes of heat and cold are common during summer and winter. Building on the central-European experience of low-energy houses and of the Passivhaus standard, the purpose here was to moderate summer overheating and reduce the use of mechanical systems also during the warm season.

The building hosts a dozen youngsters facing social problems, after the will of Don Leandro Rossi who founded a charity bearing his name. Besides the residential part, the building also includes a conference room and the offices for the charity. The volumes had to fit in a tight lot oriented North-South, which is not the best possible situation for solar energy exploitation in winter. The core of the building is the residential part, with a large, double-height living room facing South. This allows both direct solar gain during the winter and efficient natural ventilation, during summer, thanks to the stack effect activated by an operable skylight. Offices and conference areas, not necessitating solar gain because of their higher internal loads, are located in the Northern stretch of the lot. The overall surface of the building is around 630 m².

Figure 7 – The finished building from the south-west (left) and the multi-functional insulation panel before the installation of the fibre-cement cladding (right).

The goal of the design process was to provide high comfort levels with reduced purchased energy, and this was possible thanks to an envelope that works as a very efficient filter between external conditions – in particular, solar energy and winds – and desired internal temperatures. The building, in other words, is designed to behave well by mainly passive means: in winter, conserving the energy inside; in summer, limiting the overheating risk (due to both external and internal heat gains); and in the shoulder seasons, exploiting ambient temperatures outside to maintain comfortable indoor conditions.

In particular, energy efficiency during the heating season is given by a very insulated envelope (walls and roof have an average U-value of 0.11 W/m^{2}K thanks to some 28 cm insulation), where the innovative multi-functional panel described above was used for the first time, efficient windows (in wood and aluminium with average U-values of 1.4 W/m^{2}K), south-facing glazed elements to improve direct solar gains and related thermal storage capacity concentrated in the concrete slab floors. Underfloor radiant systems are used to set the indoor comfort conditions when the passive controls are not sufficient.

Figure 8 – Cross section of the building, showing the main passive devices for climate control.

During the cooling period and the shoulder seasons, while the insulated opaque envelope reduces the inbound heat flows, an operable central skylight (screened with external roller shutters when required), located above the double-height living area, can activate natural ventilation. Overheating is prevented thanks to shading from the “solar façade” (the tilted south front), from the detached roof (east and west) and from innovative, adjustable shutters. The latter, still under development, are meant to integrate perfectly with the fibre-cement rainscreen cladding used in this building, but have been designed to be replicable in other contexts. The shutter is based on insulated louvers installed on a frame that can rotate 180° on its vertical axis. Thanks to this double degree of adjustment, the shutter can provide shading under very different conditions of solar radiation (orientation, time of the day, etc.), while still allowing indirect natural light to enter the building. When closed, the louvers provide an additional degree of insulation to the glazed parts of the building shell, and reinforce the impression of the building cladding as a sort of carapace thanks to their fibre-cement cladding, that is the same of the rest of the façade. A prototype of this shutter has already been realised, and the next step will be the study of a reflective coating for the fibre-cement louvers that would enhance the ingress of indirect, natural light into the building.

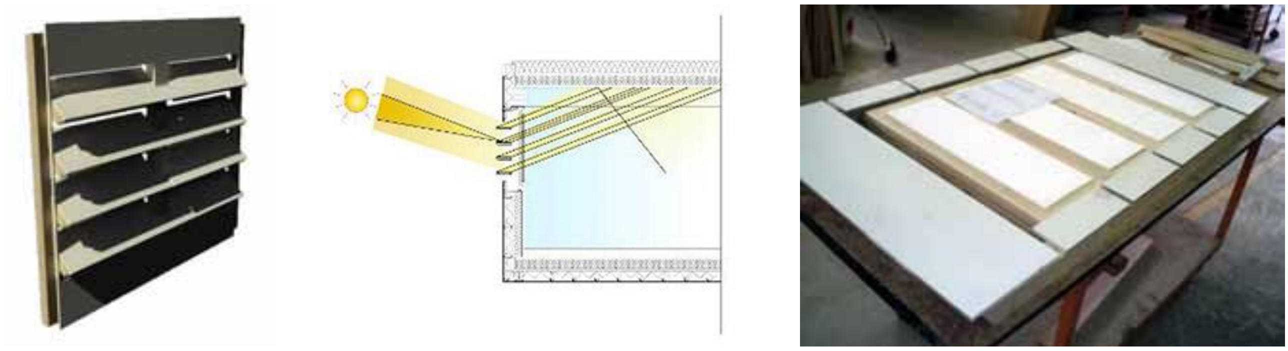

Figure 9 – The concept of the insulated, adjustable fibre-cement shutter and its prototype.

The south-facing “solar façade”, which incorporates grid-connected PV panels and is ready for the installation of solar hot water panels, produces a part of the energy required for the building operations (1,630 kWh/year).

The synergy between transparent openings, envelope/thermal insulation, shading systems, thermal effective mass and mechanical systems limits the calculated energy need for winter space heating to 6 kWh/m^3 per year. These values are well below Italian standards and place this building in “A class” according to the energy rating system adopted in Lombardy. As this building was meant to be a sort of prototype for other low-energy houses in the same climate, energy consumption and indoor comfort conditions are being monitored by the Department of Energy of Politecnico di Milano.

The possibility to integrate this innovative components in the construction mentioned before, is the result of an integrated design and construction approach coordinated by professor Ettore Zambelli. He led the design team, that included researchers at Politecnico di Milano and the engineering company Aiace based in Milan.

The building is now occupied by the client and won significant awards, such as “Next Energy Award” 2005, “EuroSolar” 2006 and “Lodi sostenibile – progettare organismi consapevoli” 2008 (under the Sustainable Energy Europe programme).

CONCLUSION

The paper showed the potential for the integration of fibre-cement products in innovative components that are suitable for the Smart-ECO very energy-efficient buildings of 2020-30. The research work conducted by the "Sustainable technological innovation" at Politecnico di Milano concerned, besides the Smart-ECO project itself, the development of a multi-functional insulated panel for rainscreen ventilated façades; the integration of phase change materials in fibre-cement internal components to provide lightweight buildings with thermal storage capacity; and the design of an insulated shutter for solar control in energy-efficient buildings. The viability of these solutions was experimented in a demonstration building containing important lessons for similar buildings in temperate climates.

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