VI International Congress on Architectural Envelopes

New industrialised developments for the envelope energy retrofitting based on heat recovery ventilation

Meno Sandra, Chica José A., Tapia Alberto (TECNALIA)
and Del Portillo Luis A. (UPV)

Division of Sustainable Construction
TECNALIA Research & Innovation (SPAIN)
sandra.meno@tecnalia.com, joseantonio.chica@tecnalia.com, alberto.tapia@tecnalia.com

Head Professor at Bilbao´s Faculty of Engineering
University of Basque Country (UPV/EHU, SPAIN)
luis.delportillo@ehu.es

Keywords: product development, dual skin facades, energy recovery ventilation, multifunctional energy efficiency façade systems, energy building retrofitting, modularity and industrialisation.

Abstract

The building envelope, in addition to climate conditions and operational resources, is considered to be the key in terms of energy consumption. This paper exposes two types of advanced envelope construction systems whose main characteristics are based on lightness, precision, modularity, flexibility and multifunctional energy efficiency façade system, dry and industrialised construction. Even though this approach goes on to be applied both new and existing buildings, energy retrofitting is intended to be the main goal in order to achieve a bioclimatic and sustainable architecture reducing at minimum the discomforts for the occupants associated to worksites. Moreover, both designs can offer energy savings compared to conventional air conditioning systems and they are compatible with the integration of renewable source systems that provide fully autonomous systems in operation phase.

The first development is a solar collection, storage and energy distribution system consisting basically of a passive dual skin, lightweight and modular facade working as a passive solar collector for a level floor that incorporates the semitransparent external layer and an internal layer with phase change materials as temporary thermal energy storage and an insulation sheet. Furthermore, a ventilation management system is powered by an intelligent controller with adaptive rollers capable of reducing the final heating consumption in the building and even to reduce the cooling consumption in the summer months.

However, the second conceptual system consists of lightweight and industrialised ventilated façade for minimizing total HVAC equipment capacity by using desiccant systems. By keeping the established requirements of the indoor air, this façade is able to optimize the thermal conditioning equipment loads

in buildings due to the ventilation requirements thanks to the possibility of energy recovery throughout the use of desiccants. Also, in order to regenerate the desiccant, the integration of renewable energies could provide a solution to improve the performance of the desiccant material and to reduce costs through any other technology.

1 Introduction

The current crisis scenario is showing the increasing need of changing the way that building construction is nowadays conceived. In order to promote a sustainable development, based on environmental, social and economic foundations, energy efficiency in renovation projects is taking extremely force. The optimization of energy performance of existing buildings is cost effective and it can and must contribute to the adaptability needed for achieving this Global Change. Energy efficiency in buildings strategy allows an optimization of energy resources consumption in order to achieve the current external dependence reduction. Moreover, there are other associated impacts, as for example CO_2 emissions, which are also reduced as consequence to promote competitiveness and market development based on energy efficiency based products. Regarding energy issues, the building sector is nowadays responsible for about 40% of primary energy consumption and one-third of greenhouse gas emissions.

The approval of the DIRECTIVE 2010/31/EU, European Union Directive on the Energy Performance of Buildings, has carried out a complete transformation of demanded requirements for both new and existing buildings, in terms of energy consumption, lighting, isolation, heating and cooling systems, hot water supply, the use of solar energy and energy certification.

Renovation, if it is carried out from a sustainability point of view, can manage up to 60% consumption savings respect of new building construction. On the other hand, it is important to remark that construction sector has not been able to advance as much as the current market requirements. Nowadays demands, not only attending to new regulations but also social requirements, become traditional construction processes inefficient. With the intention of modernizing the construction sector, in order to achieve a more sustainable development, there are many alternatives which are being developed. Industrialised construction is one of most relevant.

Industrialisation of construction [1] is understood as an organization of the production process that involves the application of advanced technologies in the comprehensive process of design, production and management, from the perspective of a logic that defines industrialisation as a combination of:

RATIONALIZATION + PREFABRICATION + AUTOMATION

Consequently, there is the urgent need for the development of more efficient and low cost (prefabricated) solutions that are modular, customizable, and also prefabricated and industrially marketable, for systemic retrofitting that can be easily applied in buildings and affordably maintained with minimum disturbances on end-users. For this challenge, two advanced facade systems based on energy recovery ventilation whose main characteristics are lightness, precision, flexibility, multifunctional energy efficiency façade system, dry and industrialised construction are exposed for energy retrofitting. Energy retrofitting is intended to be the main goal in order to achieve a bioclimatic and sustainable architecture.

2 Market study. Impact of the building renovation sector.

It is estimated by Buildings Performance Institute Europe (BPIE) [2] that there are 25 billion m^2 of useful floor space in the EU27, Switzerland and Norway. The gross floor space could be concentrated in a land area equivalent to that of Belgium (30.528 km^2). Half of the total estimated floor space is located in the North & West region of Europe while the remaining 36% and 14% are contained in the South and Central & East regions, respectively. Annual growth rates in the residential sector are around 1% while most countries encountered a decrease in the rate of new build in the recent years, reflecting the impact of the current financial crisis on the construction sector.

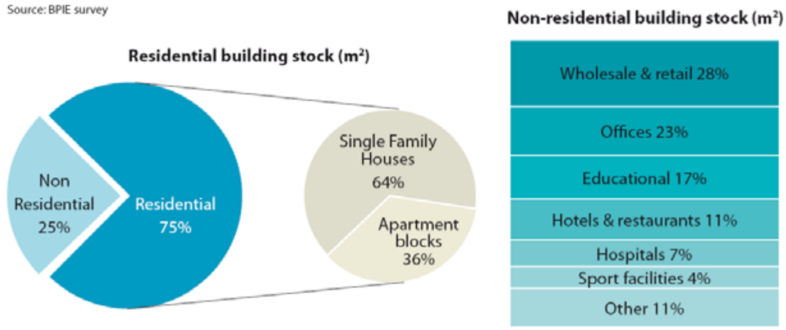

Figure 1. Residential and non-residential building stock in Europe (Source: BPIE).

A substantial share of the stock in Europe is older than 50 years with many buildings in use today that are hundreds of years old. More than 40% of our residential buildings have been constructed before the 1960s when energy building regulations were very limited. This is why building sector is one of the key consumers of energy in Europe where energy use in buildings has seen overall a rising trend over the past 20 years. In 2009, European households were responsible for 68% of the total final energy use in buildings.

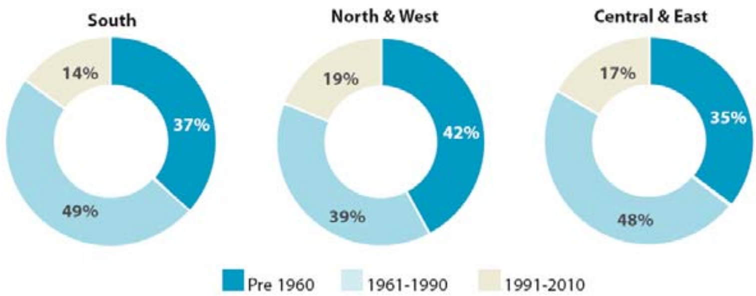

Figure 2. Age categorisation of housing stock in Europe (Source: BPIE).

The 29% of the construction sector in Europe is for rehabilitation activities, and is currently the driving force of growth of housing sector in many European countries, well ahead of the new building (18% of activity) [3].

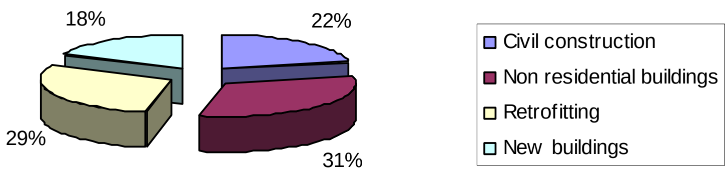

Figure 3. Distribution of the construction activity in Europe 2009 (Source: FIEC).

For the case of Spain, according to the Ministry of Housing [4], the stock of buildings is about 25 million households, of which approximately 68% are primary residences and 32% non-primary homes. The building sector in use phase during 2010 has taken the 26.1% of the annual consumption[4], divided in 17.5% for residential use and 8.6 % for commercial buildings. The energy destined to heating systems represent the 42.5% of the total, followed by the 19.6% for hot water generation and 19.4% employed in equipment, a 9.6% in lightning and finally the 8.9% that is used for cooling [5].

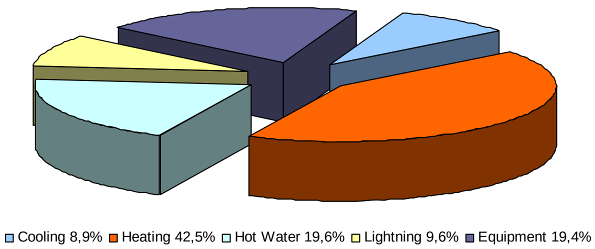

Figure 4. Energy consumption in spanish household during 2010 (Source: IDAE).

Regarding the building sector, the experimented evolution for the case of Spain is defined by a significant increase during the 1995-2007 period that has been drastically reduced after its maximum in 2007 in the so called "Boom and collapse of the Spanish building sector". As represented in the following graphs, the erected new surface's evolution has being more significant for residential purposes but has also influenced the construction of non residential new surfaces.

The similarity of the shape of the curves for new residential buildings and the total new surface generated demonstrates that there is a relation between these two magnitudes keeping a linearity that does not seem to be so clear for the cases of new non residential buildings and renovation works.

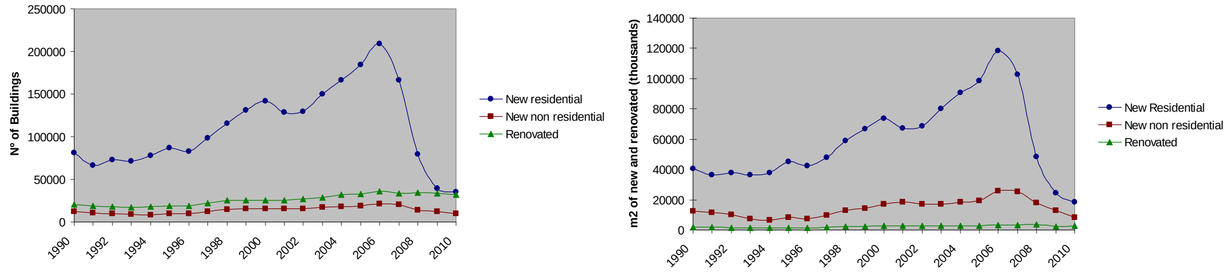

Figure 5. Evolution of works for New Residential, Non Residential and Renovation expressed in buildings (left) and surface (right).

For the case of renovation, it is also significant that this type of works have been quite unusual because in most cases instead of renovating the buildings, they were demolished and rebuilt as new ones. Even if the tendency of renovating buildings has been increasing in the last years, approaching the number of renovated building the same level as recently constructed ones, the total surface renovated barely represents the 10% of the total in the year 2010.

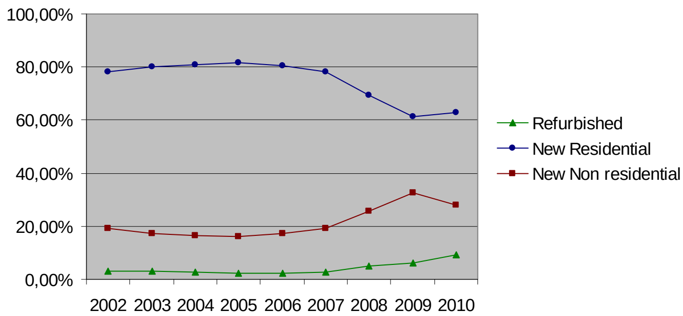

Figure 6. Weighting of the total surface refurbished and newly built.

In this context a review of the existing building stock is necessary in order to get a diagnosis of the current state of those buildings and specifically consider their energy performance to take the adequate measures for improving their contribution to the environmental impacts. Moreover, some of these buildings may need a structural refurbishment due to their high deterioration or the presence of different types of pathologies.

To get an approximate idea of the volume of the existing amount of buildings, there are some differences depending of the consulted sources instead of the difficulty to define and quantify the concept itself. The National Institute of Statistics [4] considers near 11.5 million of buildings in Spain and some other authors [6] speak about 14.18 million of total buildings.

Regarding the existing residential buildings, the National Institute of Statistics [4] gives a more accurate description of the current situation as represented in the graphs below.

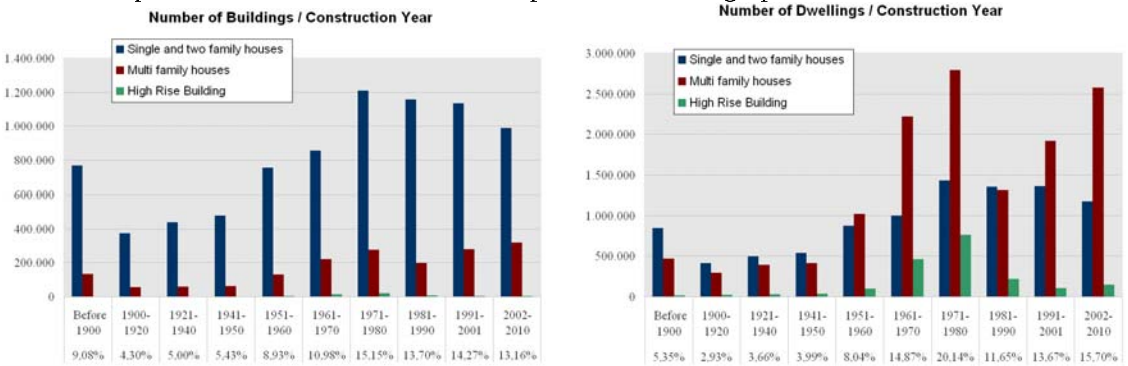

Figure 7. Analysis of existing building stock in Spain: number of buildings (left) and dwellings (right) per period.

Summarizing, there are in Spain 10 million residential buildings and 700,000 office buildings. Even if the existing stock can be considered to be quite young (the 41% is less than 30 years old), just a 6% of the total fulfills an appropriate thermal isolation level. There is an 85% that has been built with very poor insulation systems and very few of these buildings have been renovated (less than 3%) and what is even more dramatic, near a 60% of the whole building stock doesn’t even have any insulation.

It has been stated that the tendency in renovation is growing in Europe, as for example the refurbishment forecast in Spain shows, but it is important to consider that the pros and cons of constructing a new building or retrofitting an existing structure have to be individually examined and compared [8]. Renovation can reduce the energy loads by preserving building materials, which could contain high levels of embodied energy, expended in the extraction of resources, manufacture and transportation.

3 Regulatory frame

3.1 Energy Performance of Buildings Directive

At the European level, the main policy driver related to the energy use in buildings is the Energy Performance of Buildings Directive [9]. Implemented in 2002, the Directive has been recast in 2010 (EPBD Recast, 2010/31/EU) with more ambitious provisions [10]. Through the EPBD introduction, requirements for certification, inspections, training or renovation are now imposed in Member States prior to which there were very few. The transformation of the building stock in Europe into energy efficient buildings is a must in order to contribute to the objective established in the European 2020 Strategy [11]. To achieve the proposed goal in the 2020 Strategy, the European parliament and the council of the European Union have defined the DIRECTIVE 2010/31/EU [10]. The aspects to highlight of this directive are:

- More stringent requirements for energy efficiency in buildings.
- Achieve the objective of reducing by 20 % the energy consumption by 2020.

- Take into account climatic and local conditions as well as indoor climate environment and cost-effectiveness. Measures should not affect other requirements concerning buildings such as accessibility, safety and the intended use of the building.
- When buildings undergo major renovation, the energy performance must satisfy minimum energy performance requirements.
- It is known as buildings that are subject to major renovation that one that fulfils unless one of the following conditions:
    - Envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated.
    - More than 25 % of the surface of the building envelope undergoes renovation.
- Promotion of nearly zero-energy buildings, concerning the use of energy from renewable sources in existing buildings undergoing major renovation.

In Spain the “Planning actions related with energy saving and efficiency 2011-2020” [12] has a specific chapter dedicated to buildings energy performance and related to the renovation works, the “National Planning for residences and renovation 2009-2012” [13] focuses on the urgency of renovating the residential building stock.

3.2 Requirements of construction components for buildings façade

The requirements to be met by industrialized building components, for application in the façades of the buildings, as it is the case for all building products, are defined in the Construction Product Directive, CPD [14]. The CPD provides the essential requirements that products must meet to be considered suitable for their use on construction works:

1. Mechanical resistance and stability.
2. Safety in case of fire.
3. Hygiene, health and environment.
4. Safety in use.
5. Protection against use.
6. Energy economy and thermal insulation.

The CPD transposition is done at the different member states through national standards. In Spain it has been made by the Technical Building Code [15]. Next 2013 the new European Construction Products Regulation [16] will replace the old Council Directive 89/106/EEC, known as the Construction Products Directive (CPD), from year 1988. This regulation will introduce some changes in different ways in order to achieve the CE marking for construction products.

One of the main changes in this new Regulation is the following:

- The term “*Basic requirements for construction Works*” replaces the term “*essential requirements*” and it is added a 7th requirement “Sustainable use of natural resources”: The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and mainly ensures the following:
    a) reuse or recyclability for construction works, their materials and parts after its demolition.
    b) durability of the construction work.
    c) use of environmentally compatible raw and secondary materials in the construction works.

4 Passive Solar Collector Module for Building Facades

In view of the increasing energy costs and the need to reduce emissions occurring in power generation and in consumption of fossil fuels caused by the need to reduce environmental impacts, there is today a significant tendency to use “green” technologies which use solar energy in many sectors including the construction sector in which, among other systems, passive solar collectors installed in the façades of newly constructed buildings and in already existing buildings are increasingly used.

The present invention is comprised in the technical field of passive solar collectors with ventilation systems for building envelopes mainly focused on energy rehabilitation through a bioclimatic architecture. This development is a solar collection, storage and energy distribution system consisting basically of a passive dual skin façade and a lightweight and modular facade working as a passive solar collector for a level floor. The concept is based on passive dual-layer bioclimatic configurations which are integrated into a unique module facade. The system consists mainly on:

- External layer: semitransparent glazing. (Figure 9, number 1).
- Inside layer: a lightweight high inertia internal wall with encapsulated phase change materials (PCM) as thermal energy storage and an insulation layer. (Figure 9, number 2 and 16).
- Air chamber: air circulation space between them (Figure 9, number 15).
- Intelligent controller with adaptive rollers (Figure 9, number 13 and 14).
- Automatic roller blind system (Figure 9, number 22).

This product development (Patent PCT WO/2011/080356 [17]) allows the advanced ventilation management in passive solar collectors. It can manage the ventilation patterns of most widespread bioclimatic passive systems (trombe wall, parietodynamic wall, ventilated façade, solar wall, solar chimney and passive cooling), all of them integrated in the same technological module unit. The proper functioning of the system and its basic configuration depend directly on the specific climatic zone, the season and the daytime or night-time period.

This level of integration of passive bioclimatic systems into a modular concept has never been achieved. This system doesn't require necessarily additional HVAC equipment, and thus is passive concerning its energy consumption. Even being a passive system, it is actively controlled, which extends its functionalities beyond traditional dual layer façades. The main innovation of this system is an air flow controlling adaptive roller systems that selects the most appropriate airflow pattern in the collector. The system also includes a cladding element, which prevents heat dissipation in the absence of sun in winter and prevents day heating in summer. The louver system and cladding element are intended to function as part of an intelligent building-level integrated system. This way, the most appropriate functioning mode –heating, ventilation or cooling - will be provided depending on the external conditions and user needs. This advanced passive solar collector technological unit that allows different ventilation modes in order to achieve the maximum energy efficiency and cost-effectiveness for different climatic zones.

Based on normative UNE EN 832 [18] and UNE EN ISO 13790 [19], the model used corresponds to a concentrated parameter model given by an electrothermal analogy to develop the theoretical energy simulations for four climatic zones in Spain with all the different basic configurations and materials of the layers, including the diversity of original building facade.

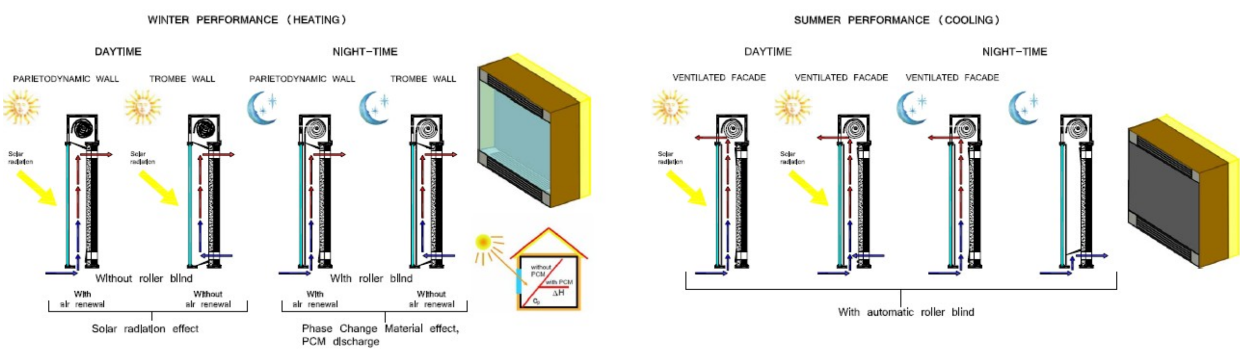

Figure 8. Schematic operation patterns of the module (day/night-time, summer/winter)

In the next figure there are reference numbers identifying the following elements of the passive solar collector modules for the envelope energy retrofitting:

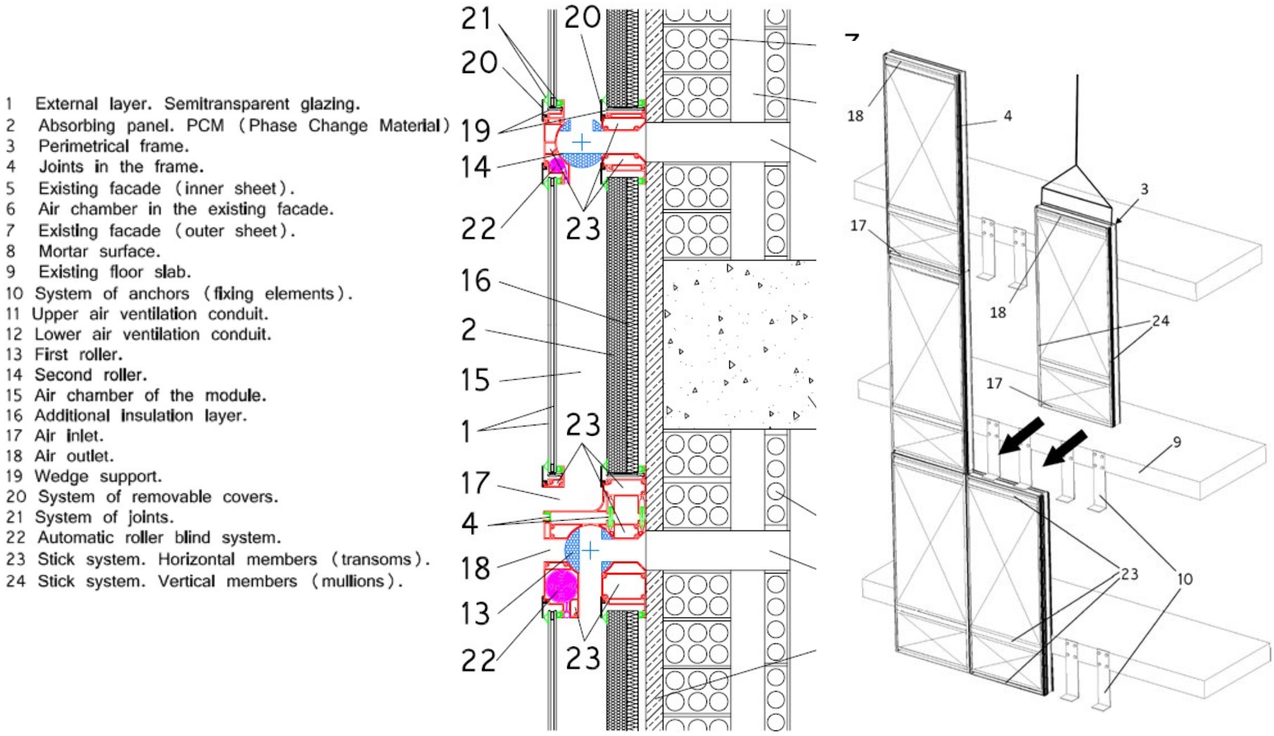

Figure 9. Schematic view of a complete module

A phase-change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. PCMs are ideal products for thermal management solutions. Phase change materials help to utilize the so-called latent heat. The latent heat is energy which released or absorbed during the phase change of a substance. Latent heat can be absorbed or released, for example, when a substance changes phase from solid to liquid form [20]. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade and currently under research and development. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications [21, 22]. The most commonly used PCMs are salt hydrates, fatty acids and esters, and various paraffins. The selected products for the energy simulations were different types (components and micro/macro-encapsulation) of PCMs with phase change temperature of 24-26 ºC and with thickness between 15-30 cm depending on the climatic zones.

This conceptual product development is one of the different modular envelope systems that will be entirely optimised, adapted, developed and manufactured in project “MeeFS Retrofitting. Multifunctional Energy Efficient Façade System for Building Retrofitting" during 48 months with 16 partners. This project has been co-financed in Seventh Framework Programme (FP7) [23] by European Commission. MeeFS aims to develop, evaluate and demonstrate an innovative energy efficient multifunctional façade system geared towards the residential building sector.

5 Industrialised Ventilated Façade for energy recovery ventilation using desiccants

The requirement for ventilation air or renovation of buildings is relatively recent, as a compulsory measure to be taken, and is established in the different countries by the relevant national legislation, e.g. for Spain the Spanish Technical Building Code [15] and the Regulations on Building Heating Installations, RITE [24].

As result, it is necessary to be provided a sufficient flow of outside air to allow the evacuation of stale indoor air. Obviously, the use of outside air ventilation implies an increase in thermal loads conditioning equipment, mainly due to its temperature and humidity content. Air change (renovation and infiltration) accounts for approximately 36% of total space conditioning energy and contributes to almost half of heating equipment losses [25]. It should be pointed out that; relative humidity at the indoor environment of buildings must be within a specific range for human comfort [26].

The desiccant based air-conditioning system comes to be one of the prospective alternatives for the traditional vapour-compression air-conditioning systems [27]. Separating the control of humidity and temperature using a desiccant could result in energy savings and improved humidity control.

Therefore, the main objective of this design and development of an industrialised ventilated façade system, which, by keeping the established requirements for the indoor air renovation, is able to minimize energy demand and thermal loads on HVAC (Heating, Ventilation and Air Conditioning) , thanks to the possibility of air ventilation pre-treatment by using desiccant materials.

Conceptual development

Recently, the rapid development of desiccant air conditioning technology, which can handle sensible and latent heat loads independently without using CFCs and consuming a large amount of electric power, and thus meet the current demands of occupant comfort, energy saving and environmental protection, has expanded desiccant industry to a broader niche applications, such as hospitals, supermarkets, restaurants, theatres, schools and office buildings.

Desiccants are materials with a high tendency to adsorb water. If a dry desiccant is exposed to the air, it will dehumidify the air, while the desiccant becomes warm. Eventually the desiccant will become saturated with water, but it can be "regenerated" by heating. The desiccant materials are substances that have a great affinity for water, a property that allows them to trap humidity from the surrounding air. This process is called drying and involves, in addition to dehumidification, heating of the air stream, given that there is a replacement of the moisture-latent load by an increase in its temperature-sensitive load.

The physical process, which allows the humidity retention or release, is the existing difference between the desiccant surface and the outside air vapour pressure. This process is named adsorption when the desiccant material is in a solid state and absorption when it is in a liquid state. Sorption process consists of the adherence of atoms, molecules or ions to a surface. It is called adsorption when Van der Waals forces are present (physic phenomenon) and absorption when chemical bonding between absorbed substance and surface are the forces present (chemical sorption). The adsorption occurs when no physical or chemical change is produced on desiccant surface.

Solid desiccants capture humidity in a first phase because of the electric field strength present on his surface (Van der Waals forces). When surface is already full, desiccant continues capturing humidity because water is driven to and retain, in the numerous pores and capillaries contained in its grains. The surface of this condensate water is concave because of the surface tension. This concave causes less vapour pressure, so the attraction of water from the air current surrounding the desiccant, continues until equilibrium is got. An image of this process for a silica-gel grain is shown on Fig. 10.

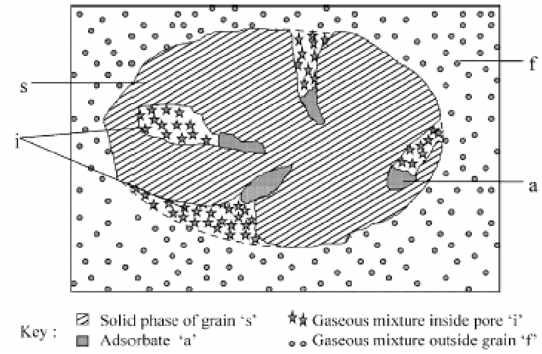

Figure 10. Four adsorption phases on a silica-gel grain.

Finally, it should be mentioned that, desiccant need to be regenerated for further use. This means that all the water has to be desorbed and desiccant comes dry. Thermal energy is used for desorption, and the utilization of solar energy and other low grade heat sources, such as district heating, waste heat and bio energy, together with the development of new desiccant materials and novel system configurations have had significant relevance on air conditioning applications.

This low grade heat sources are mainly applicable for solid desiccants as; silica gel, activated carbon, activated alúmina and molecular sieves (about 60ºC). Liquid ones as; lithium chloride, lithium bromide, calcium chloride, and triethylene glycol, precise high heat sources for regeneration which means expensive high temperature solar collectors.

Another of the challenges in the proposal is to integrate solar thermal systems for regeneration of the desiccant, for example solar air collectors. Moreover, the integration of other renewable sources, as photovoltaic modules (PV), will supply the needed electric power in the system operation phase.

The integration of PV in the urban environment and buildings (also called BIPV, Building Integrated Photovoltaic) offers a vast potential: environmental and economic benefits, encouragement of technological innovations, trends towards bioclimatic architecture, the anticipated supporting legislation, etc. and the possibilities for BIPV are unlimited. In addition to PV conversion, with the right design they can also provide weather and acoustic protection, thermal regulation, shading, and many other constructive functions.

Summarising, the idea is to integrate an industrialised ventilated façade for retrofitting buildings (it could be applied to new construction) with the ventilation system and air handling thermal energy by taking advantage of air between the existing façade and the new skin optimizing HVAC equipment capacity:

- Development of an industrialised ventilated façade for retrofitting which allows energy-saving (in heating or cooling loads depending on the specific climatic zone, mainly regarding temperatures and relative humidity). Industrialization does not necessarily imply the use of new materials, but new forms of application or combination of materials, manufacturing construction components in facilities outside the place of final assembly. This way, it seeks to reduce the work on site to maximize the work shop or factory with controlled production.
- Determine which of the solid or liquid desiccant materials in the market will be the best for its application. Initially, silica gel has been considered as the most properly desiccant for this application within this first research phase.

- The incorporation of different renewable energy sources as for example solar air collectors to regenerate the desiccants properly. For this objective the Passive Solar Collector Module exposed before, could be one of the possibilities of integration in order to regenerate the desiccant in this ventilated module.

The innovation on this proposal will allow providing to the ventilated façade systems an extra feature done in an industrialised way, getting a standardization to allow the feasibility of industrial production. The integration of desiccant materials for air-conditioning will allow to incorporate concepts related to energy saving and environmental benefits.

This concept is one of the different systems that will be entirely developed in the FP7 project [23] "RetroKit - Toolboxes for systemic retrofitting" during 48 months. RetroKit project will research the optimum costs and energy saving actively and will develop and demonstrate at three building pilots, multifunctional, modular, low cost and easy to install different prefabricated modules in order to significantly increase the EU retrofitting rate and contribute to EU energy reduction commitments.

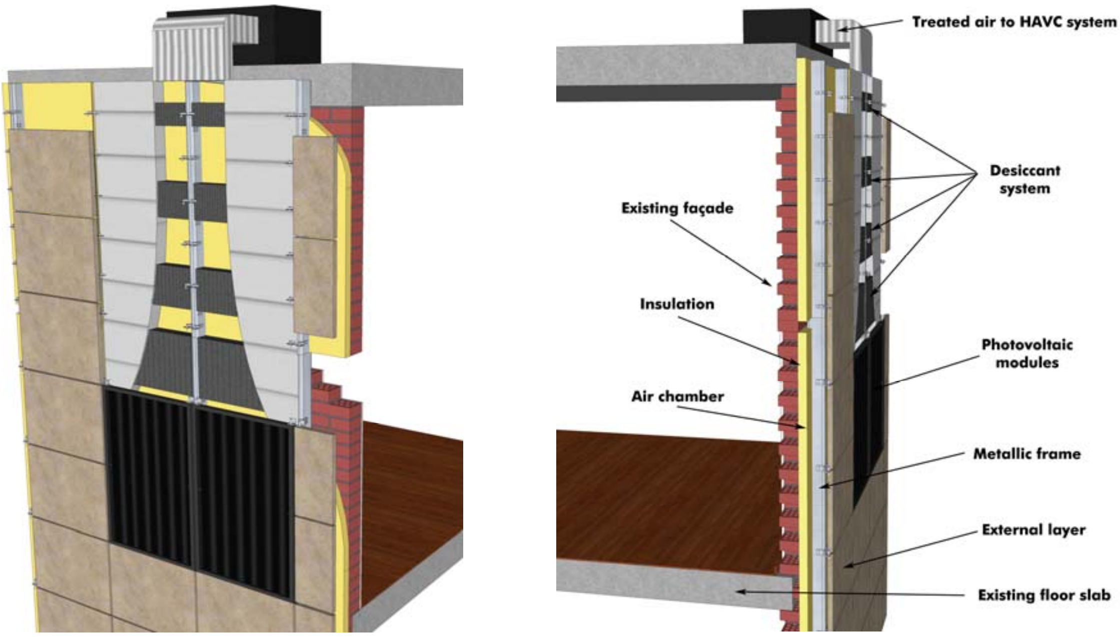

Figure 11. Schematic sketches of the conceptual design.

Acknowledgements

Currently, the final design and optimisation of these research works will be developed in FP7 projects [23], co-financed by the European Commission: "MeeFS Retrofitting. Multifunctional Energy Efficient Façade System for Building Retrofitting" (www.meefs-retrofitting.eu) and "RetroKit. Toolboxes for systemic retrofitting" projects.

References

[1] La Industrialización de la edificación de viviendas, Alfonso del Águila García, 2006.

[2] Buildings Performance Institute Europe (BPIE) (Europe's Buildings under the Microscope. *Europe's buildings under the microscope. BPIE October 2011. ISBN: 9789491143014*, www.bpie.eu.

[3] "Construction in Europe 2009", FIEC, Federación de la Industria de la Construcción Europea, 2010.

[4] National Statistics Institute, http://www.ine.es/.

[5] The Institute for Energy Diversification and Saving of Spain, IDAE, "Planning actions related with energy saving and efficiency 2011-2020. 2nd National Plan for Energy Efficiency in Spain".

[6] Development of European Ecolabel and Green Public Procurement Criteria for Office Buildings. JRC IPTS Draft Preliminary Study (2011), "*Economical and market analysis*".

[7] José A. Orosaa & Armando C. Oliveira, "Energy saving with passive climate control methods in Spanish office buildings". Energy and Buildings. Volume 41, Issue 8, August 2009, Pages 823–828.

[8] UNEP. Green Economy Report. 2011

[9] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings.

[10] European Union Directive on the Energy Performance of Building. EPBD Recast, 2010/31/EU.

[11] European 2020 Strategy, http://ec.europa.eu/europe2020/.

[12] Planning actions related with energy saving and efficiency 2011-2020, http://www.minetur.gob.es/energia/es-es/novedades/paginas/paaee_2011_2020.aspx.

[13] "National Planning for residences and renovation 2009-2012", http://www.fomento.gob.es/.

[14] Construction Product Directive, http://europa.eu/legislation_summaries/other/l21184_en.htm.

[15] Código Técnico de la Edificación, CTE, www.codigotecnico.org.

[16] Regulation EU No.305/2011 of the European Parliament and of the Council of 9th March 2011

[17] Patent PCT WO/2011/080356 A1 in July 2011 by Fundación Labein, Tecnalia.

[18] UNE EN 832: 2000 "Thermal performance of buildings. Calculation of energy use for heating. Residential buildings".

[19] UNE EN ISO 13790: 2008 "Energy performance of buildings. Calculation of energy use for space heating and cooling".

[20] Knaack, Ulrich, Klein, Tillmann, Bilow, Marcel, Auer, Thomas. Façades -Principles of Construction, 2007. Available at SpringerLink.

[21] Review on thermal energy storage with phase change materials and applications Atul Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, 2007.

[22] Solar energy storage using phase change materials, Murat Kenisarin and Khamid Mahkamov, School of Engineering, University of Durham, South Road, Durham, DH1 3LE, UK, 2006.

[23] Seventh Framework Programme, http://cordis.europa.eu/fp7/.

[24] Regulations on Building Heating Installations, RITE http://www.idae.es/index.php/relcategoria.1030/id.430/relmenu.347/mod.pags/mem.detalle.

[25] Energy and Ventilation. M.W. Liddament and M. Orme (Air, infiltration and ventilation Centre).

[26] ASHRAE, Handbook of Fundamental, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc, Atlanta, USA, 2001.

[27] A.V. Arundel, E.M. Sterling, J.H. Bigging, T.D. Sterling, Indirect health effects of relative humidity in indoor environments, Environmental Health Perspectives 65 (1986) 351–361.