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Energy efficiency achievements in 5 years through experimental research in KUBIK

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Abstract

The European construction sector (a fragmented SMEs dominated business with high economic and environmental impact and high technological inertia) faces a major challenge to reduce the emissions by almost 90% in 2050. This requires new innovative solutions and services to be rapidly implemented in the market. Research Infrastructures that give support for later-stage developments (high Technology Readiness Levels) can play a relevant role in both the technological development and market introduction of construction products for energy efficient buildings. The following paper describes such an infrastructure ($KUBIK_{by\ Tecnalia}$) located in Bilbao (Spain) and its major outcomes in the period 2011-2015.

Keywords: Energy efficiency; R&D infrastructure

1. Introduction

The document "A Roadmap for moving to a competitive low carbon economy in 2050" [1] published by the European Commission in 2011 sets up a European scenario to keep climate change below 2ºC by reducing the greenhouse gas (GHG) emissions by 80-95% by 2050. The Europe2020 flagship initiative for a resource-efficient Europe [2] details the reduction of GHG emissions in the period until 2020 per sectors. Buildings in Europe generate 36% of GHG and 40% of total energy consumption, and therefore are key enablers of the 2050 decarbonisation goal [3]. The European Commission brings the 2050 decarbonisation strategy into Directives, which in the construction

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sector are the Energy Performance Building Directive (EPBD) and its recast [4], and the Energy Efficiency Directive. The EPBD-recast Directive enforces new buildings in Europe to be nearly zero energy buildings (nZEB) from 2019 onwards. The Energy Efficiency Directive [5] targets the retrofitting of public buildings (owned or occupied by the central governments) from 1 January 2014 to a minimum of 3% per year. This new set of Directives requires the European Construction sector to strength the innovation capabilities and to increase the market uptake of new developments.

But the construction sector is highly conservative and low-innovative (business enterprise R&D expenditure are very low [6] when compared with other sectors) with a high potential impact in the European economy and environment [7]. Among the identified barriers for market up-take of energy efficient new buildings and existing buildings' retrofitting, the most relevant is the considerable upfront funding required [8]. This makes risk diminishing activities critical to facilitate market introduction of any innovative product in the construction sector.

Moreover, the construction sector is very fragmented, not only in terms of size of companies (over 95% are SMEs) but also in terms of diverse typology of stakeholders in the value chain. These factors increase the complexity of introducing innovation making necessary strong alignments.

2. Nearly Zero Energy Buildings "nZEB" and energy renovation in Europe

New buildings in Europe will be required to be nearly zero energy buildings from 2019. Research at an international level on building energy efficiency allows concluding that to achieve nZEB is necessary the resolution of a trinomial expression made up of [9]:

- Improvements of buildings thermal performance, through architectural or constructive solutions basically improving the envelope performance
- Energy consumption reduction through rational use for air conditioning, illumination and ventilation of living spaces, supported by intelligent management systems (BEMSs)
- Increasing energy generation based on renewable energies at building level and its proximity (distributed generation and multi-generation management) handing over partial responsibility to the building for the generation of the energy needed to supply its activities

It is the combination of activities in these 3 areas what makes buildings be nearly zero energy buildings. Innovation is required in the 3 dimensions to accelerate nZEB market uptake.

Fig 1 External view of the Kubik $_{\text{by Tecnalia}}$ test facility

With regard to existing buildings, an increased renovation rate and depth of the renovation (measured as % of energy saving) is crucial for achieving the Europe-2020 and -2050 decarbonisation targets. Existing buildings are renovated every 30 to 40 years [10] on average, and every 60 to 80 years in the Mediterranean countries [11]. Renovation rate in Europe today is between 1% and 2% per year [8]. Predictive models indicate the need to increase the renovation rate to a minimum average of 3% per year thus increase the depth of renovation to allow achieving decarbonisation targets.

Innovation is required to (1) improve the performance of the building envelope, (2) improve the management of energy equipment, and (3) improve the user acceptance thus reducing misuses.

3. KUBIK aims and experimental capabilities: Research infrastructures as leverage factor

KUBIK$_{\text{by Tecnalia}}$ (hereinafter referred to as KUBIK) is a full scale experimental infrastructure for R & D + I on energy efficiency, focused on the development of new products and systems that provide energy consumption reduction for the building whilst improve user comfort and health indoor environment.

KUBIK has the experimental capabilities that allow the validation of innovative products and systems in service conditions that may accelerate their introduction to the market. The main distinctive feature of KUBIK is its capacity to create realistic scenarios for the investigation of energy efficiency resulting from the interaction of constructive solutions, the intelligent management of HVAC and lighting systems and non-renewable and renewable combinations of energy supplies.

The infrastructure is a building enclosing a maximum of 500 m^2 distributed over a basement, a ground floor and a further two levels. The supply of energy is based on the combination of conventional and renewable energies. The infrastructure is configurable in (1) its envelope (façades, windows, roof, shading systems), (2) its internal partitioning (open layout, large spaces, small spaces), (3) its HVAC system (type of diffusing system, ventilation, HVAC plant…), and (4) in the building management system [12].

KUBIK supports developments at high TRLs in products and services to be launched into the market, accelerating the uptake of new innovative solutions through their co-development with the relevant stakeholders in the construction sector under realistic use conditions.

KUBIK is an open research infrastructure to be used by the industry, research centers, public administrations and standardization bodies. New solutions can be shown to the market (different stakeholders in the value chain).

4. KUBIK capabilities at a glance: FIEMSER and ReFaVent projects

Following is the description of the activities developed in KUBIK in the frame of two research projects: FIEMSER and REFAVEN.

4.1. FIEMSER

FIEMSER system, an innovative Building Energy Management System (BEMS), was validated in KUBIK. Current BEMSs have several weaknesses: predefined energy control strategies, lack of integration of the local energy generation with the building energy consumption, lighting system decoupled from the HVAC system, wired control networks, limited interoperability, etc. FIEMSER system defines dynamic and holistic control strategies that take into account the current and future building operating conditions (building users activities, weather conditions, energy prices, etc.) and integrates the different energy related subsystems: HVAC, lighting, local generation and energy storage. FIEMSER system leverages on the Service-Oriented Architecture (SOA) paradigm with the definition of modular service interfaces. This paradigm provides the necessary flexibility to: (1) adapt the system to the different configurations, (2) integrate existing control protocols and emerging wireless ones, and (3) support different GUI (Graphical User Interface).

FIEMSER System is an innovative Building Energy Management System (BEMS) for existing and new residential buildings, which pursues the increase of the efficiency of the energy used and the reduction of the global energy demand of the building, but without penalizing the comfort levels of the users. In order to achieve this goal, two main strategies are followed:

- Minimizing the energy demand from external resources, through the reduction of the energy consumption in the building and the correct management of local generation and energy storage equipment to satisfy the energy demand of the building, and even provide the capability to export energy to the utilities when needed.
- Interaction with the building user, in order to increase the consciousness of the consumer about his energy consumption, providing hints to make punctual changes in his behaviour without major disruptions of his comfort conditions.

The deployment of the FIEMSER system in KUBIK represented an apartment that has its own connection (and meter) to the electrical grid and takes hot/cold water for air conditioning from communal services. Also RES are managed as communal services.

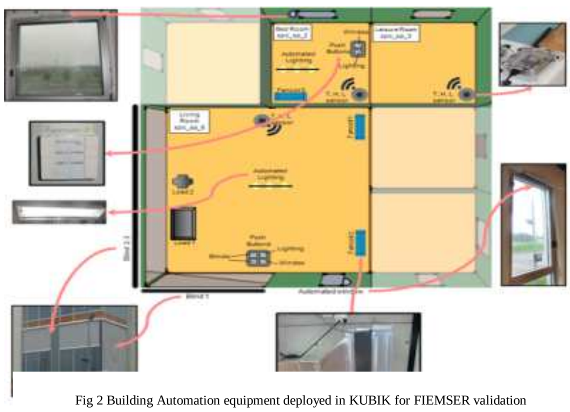

Fig 2 Building Automation equipment deployed in KUBIK for FIEMSER validation

The apartment was composed by six cells (testing minimal unit in KUBIK) in the 1st floor of the building was distributed configuring three rooms: living room (four cells), bedroom (1 cell) and leisure room (1 cell). These rooms were in the East, South and West facades.

Figure 2 shows the location of some components of the testing scenario, with photographs of the most relevant devices.

FIEMSER validation defined metrics, performance indicators and validations domains in order to have a proper picture of the overall FIEMSER project performance after the finishing the validation process.

- System wide validation domain: This validation domain covered verification of the appropriate operation of each of the installed systems (automated windows, blinds,..)
- Functionalities validation domain: The functionality validation domain covered the verification of the forecasts and operation schedules released by the FIEMSER.
- Energy validation domain: Top validation domain. Supported by the previous validation steps, covered the validation of FIEMSER in terms of energy savings and efficiency.

FIEMSER´s validation in KUBIK considered the reference model to be the simulation.

The achieved measured savings by implementing FIEMSER system were 26,5% for lighting, 8,7% for heating and 80,5% for cooling.

4.2. REFAVEN

REFAVEN project investigated on the suitability of ventilated façades as external thermal insulation systems for the refurbishment of the building stock. Research was conducted on the modification of the heat transfer, not only through traditional brick façades, but also on the modification of the thermal field in thermal bridge areas such as those in façade-slab junctions.

For this purpose, a sub-sector of two test-rooms in a vertical arrangement was conditioned in KUBIK. A west-oriented test façade was constructed in these rooms, which comprised 3 façade-slab junction elements, constructed in equivalent materials and thicknesses to those present in the Spanish building stock.

Figure 3: Left: Building with brick façade, Center-left: Calibration façade test configuration in KUBIK (phase 0), Center-right: Brick façade test configuration in KUBIK (phase 1), Right: Ventilated façade solution in KUBIK (phase 2)

These elements were located at slab level coincident with 1st, 2nd and roof level slabs in KUBIK. A sequence of façades was tested:

• Phase 0: Highly insulated sandwich façade
• Phase 1: Brick cavity façade
• Phase 2: Ventilated façade refurbishment of brick cavity façade

In all three phases, the effect of the building fabric within the thermal balance of the building was experimentally evaluated. Prior to experimentation, thermography and airtightness tests were performed to minimize uncertainties related to unexpected phenomena.

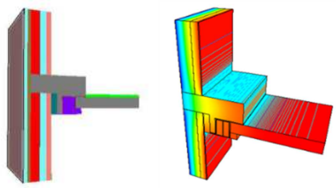

Figure 4: Finite difference models of the slab-façade junction at floor level 2

Heat flows (1- and 2-dimensional) were subjected to measurement and calibration. 1-D heat transfer was modeled through calibrated state-space models, and 2-D heat transfer through calibrated FDM. These models, jointly with a heat balance approach to the test set-up provided the backbone of the energy assessment needed for the REFAVEN project.

The outstanding conclusions of this study was that the selected ventilated façade reduced the overall heat flow across the façade by 50%, and that thermal bridges (which accounted for 20% of the overall energy flows) were minimized by 50%. Ventilated façades were also effective in reducing solar heat gains in summer period.

5. KUBIK achievements in 5 years of operation

In the period 2011 to 2015, a total of 21 projects (7 on-going, 3 starting and 11 finished) have had KUBIK as research platform. The vast majority (18) of these projects is EU-funded, and only 3 of them were supported by the industry.

Most projects (16) involved the development of building components, 7 of them for retrofitting of buildings. In total 4 intelligent management systems (building-demand and on-site generation management) related project were implemented in KUBIK, whilst only 1 project tackled the management of distributed energy generation.

Table 1. Testing period in KUBIK

Period	Number of projects
1 to 1.5 years	9
6 months to 1 year	6
3 to 6 months	2
Less than 3 months	4

Two patents have been obtained in the frame of KUBIK activities: (1) Passive Solar Collector Module for Building Envelopes (09812437.3, EP 2520 870 A1), (2) Photovoltaic Module for Curtain Walls (PCT/ES2011/070902, WO/2012/089883 A2). In addition, one utility model has been developed: Prefabricated Façade (Utility Model application: U200930530, ES 1 071 274 U).

Regarding visitors to the infrastructure, a total of 1.138 people have visited KUBIK in the period 2011-2015, spread as follows:

Table 2. Number of visitors in Kubik

Period	Number of visitors
2011	109
2012	325
2013	321
2014	383
TOTAL	1.138

Table 3. Visitors per type

Type of visitor	%
Educational Centers	17.3
Research Centers	10.3
Industries	37.2
Consulting	7.1
Public administration	13.5
Architects	3.2
Platforms, clusters, associations, etc.	11.5

The typologies of industries visiting KUBIK are as follows:

Table 4. Type of visiting industries

Type of industry	%
Construction	39.3
Electr./Telecom.	4.9
Equipment	13.1
Renewables	4.9
Labs	3.3
Real Estate	4.9
Others	29.5

Table 5. Visitors per country of origin

Country	%
USA	1.3
Asia & middle east	3.3
Latin-America	11.2
Europe	84.2

The technical activity associated with deployments in KUBIK in the period 2011-2015 totalized 1.029.467€, equivalent to 3,3 Persons/Year.

6. Conclusions

KUBIK provides the needed support to improve the energy performance at building level, as requested by the Energy Performance Building Directive (EPBD), and in a comprehensive way, the envelope, the demand and energy generation. KUBIK allows developing and validating innovative products and systems to optimize energy efficiency in buildings, from its conceptualization to its implementation.

The potential of KUBIK is to mobilize the stakeholders towards a more innovative and added-value business in the field of energy efficiency in buildings and urban areas. As the European Commission is forcing new buildings to reduce the energy consumption thus increase the share of energy generation from renewable sources, this is promoting new business models which are a starting basis for new companies (start-up) as well as for bringing innovation to the activity of existing ones towards what will be the future of the construction sector.

7. Acknowledgements

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