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CONTENT

Building automation solutions applied to the building envelope: mapping the market and development prospects

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Abstract

This research, carried out by Polytechnic of Milan, has mapped out the offer available on the market with regards to the solutions of home and building automation systems applied to the building's envelope and of the vertical closure of tertiary buildings, in order to highlight the automation solutions existing today and the development prospects that may arise in the future.

Keywords: Building automation, intelligent skin, building envelope designer, technological performance, automation systems, energy consumption.

1. Stage of research

The research was structured in four main phases. First of all, a research and development analysis has been made on an international level related to the automation concept of the building envelope. In this phase we have analyzed the areas/research activities conducted by leading universities worldwide, in an attempt to determine the emerging areas and trends.

Since the goal of research is to collect qualitative data surrounding a building's performance as well as the state of the art automation systems applied to buildings, we developed a questionnaire for the collection of standardized and comparable data. During the third phase, we analyzed the attention of designers towards solutions relating to the concept of "intelligent skin" and the current market availability of systems capable of interfacing with the building envelope.

Finally, the data we have processed revealed the following:

a. the main solutions adopted today relatively to automation systems;
b. performance/parameters considered crucial by the market, particularly focusing on issues related to the benefits of facade management and its contribution to reducing energy consumption as well as to the performance of the building;
c. the relationship between automation/control systems, vertical closure and control systems.

2. Trends at the international level related to the concept of automation for buildings

One of the main research activities in the building automation field at several international universities addresses the application of a particular field of electronics research to the construction industry for the development of so-called *Wireless Sensor Networks* [1].

A WSN is a network constituted by a set of sensors (nodes) distributed in the environment, which cooperate with each other in order to detect phenomena and physical parameters. These nodes are able to gather information and to communicate it to a base station, in very short time, through network protocols. The data are transmitted wirelessly to the control system which processes them and, if necessary, activates some commands. Nodes can be very small, but they manage to incorporate within them: sensors, processors, radio transmitters, software and power systems; for this reason they are also nicknamed *Smart Dust*. The elements constituting the sensors are the so-called MEMS (*Micro Electro-Mechanical Systems*). These control points can, for example, be inserted in the walls to detect temperature, humidity, level of volatile organic compounds, etc. [2].

Technological research has developed sensors that may be included in glass sheets for measuring the mean radiant temperature and MEMS that can record the passage of CO_2 molecules through a change in voltage: these elements are so tiny that they are able to generate the electricity with which they are powered through slight vibrations of the ducts or building in general.

2.1 International research centres

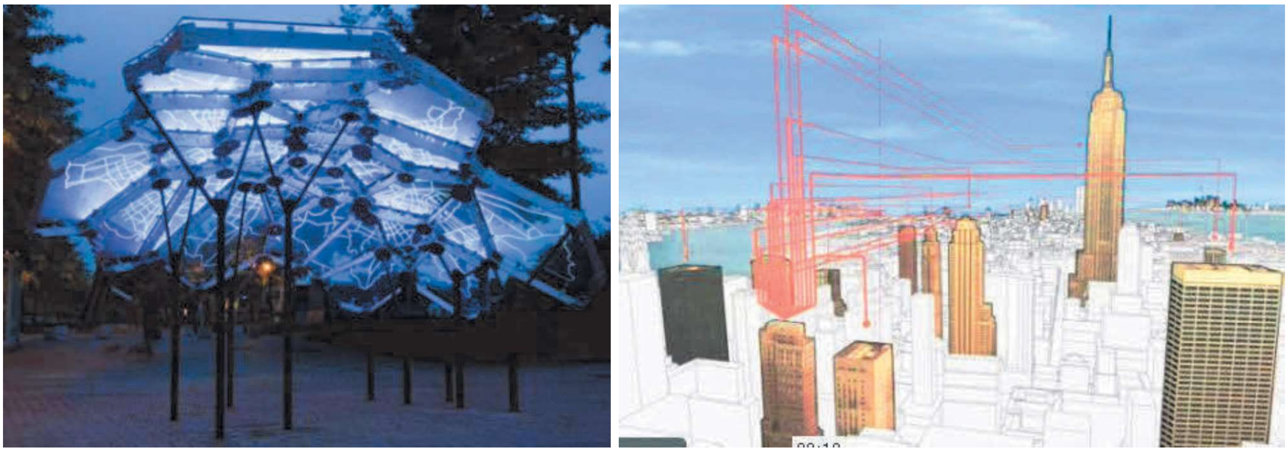
2.1.1. CBE Centre for the Built Environment (University of California, Berkeley)

The CBE Centre has studied the application of WSN to buildings, in particular, in reference to the control of the quality of indoor environment parameters (temperature, air quality and lighting). Two projects were developed for as many buildings existing on the campus: a 100-sensor network operated by a PC was installed in one of the buildings, allowing control of the temperature and lighting levels in an area of the building in order to monitor energy consumption. A lighting control system was installed in the other building (offices) which allowed, each occupant, to adjust light levels through a remote control. According to the CBE Centre for the Built Environment, the cost of wiring a building with control points and sensors can represent 50-90% of the installation cost.

Wireless and MEMS technologies can reduce these costs, allowing also an improvement in the quality control of the environment and important energy savings [3].

2.1.2. Living Architecture Lab - Graduate School of Architecture, Planning and Preservation (GSAPP), Columbia University

The Laboratory investigates the possibilities of architecture to transform itself in real time in response to the action of the "invisible forces that shape the world": lights that change colour depending on the change of air or water quality, materials that vary in appearance depending on the occupation requirements of the spaces in the course of days or years. The laboratory designs and produces life-size functional prototypes based on components capable of recording input data, processing them and returning output information. Among the reported projects we can mention:



Figures 1-2: The illuminated pavilion of the living light project (Left) and the transmission system between the living city project buildings (right).

- Living light: it is a project commissioned by the City Gallery and the Municipal Government of the City of Seoul. It is a permanent outdoor pavilion, placed in the centre of Seoul with a dynamic surface that lights up depending on air quality and the interest of citizens to the environment. The lighting control system is connected to a server processing real-time data from the web site of the air monitoring system and comparing them with yesterday's data. If the air quality improves, the corresponding neighbourhood panel lights up. When citizens request an SMS from the web site to get information on the air quality of a neighbourhood, the lights on the relative panel start flashing (see figure 1).

- Living city: the concept behind this project is that the facades of the buildings and access to the area constitute the frontiers of public spaces in urban areas and that, in the future, the facades will be at the service of the residents like it is today for parks and streets. According to the designers, architects David Benjamin and Soo-in Yang, facades should be active, able to collect data, transmit, react to the surroundings and interact with the other buildings to create an information network. The team designed a system of sensors that can be installed outside the building to collect data on carbon monoxide and nitrogen in the air. Some prototype sensors were placed on the Empire State Building and three other buildings in Manhattan, to test the capacity to collect and communicate information. The next phase saw the buildings respond to data: the team designed prototypes of slats that open or close depending on the air quality [4] (see figure 2).

2.1.3. Hong Kong University (HKU) - Strategic Research Areas and Themes

In 2008, the HKU identified five strategic areas of research, including that of Frontier Technology. Within this area, research aimed at improving the efficiency of WSNs in terms of energy consumption and operational performance. Researchers at the HKU are looking to:

- establish correlations between the information gathered by the various sensors so as to select the data to be sent and consume less energy;
- classify the energy required to process and that to transmit the data;
- propose a protocol for energy efficient WSNs;
- studying how to activate the "sleep mode" of the sensors, when they are not operating, to save power.

3. Construction of the questionnaire for the collection of data

Since the aim of the research is the collection of qualitative information concerning the performance of buildings and state of the art of automation systems (home automation and building automation systems) applied to buildings, a questionnaire has been constructed (in the form of a checklist) for collecting consistent and comparable data.

3.1 Questionnaire for designers

The survey questionnaire submitted to designers consists of three parts:

1. A description sheet, where there are a number of items concerning the property being analysed;
2. A sequence of sheets relating to the technological/descriptive aspects of the structure, its performance and the intelligence features relating to the property;
3. A section dedicated to further study of the project (design features, costs and construction times, intelligent/home automation solutions integrated in the building, etc.).

In particular, the second part of the questionnaire is divided into five areas of analysis, each of which was in turn divided into groups and subgroups. These are [5]:

1. Building envelope: aspect ratio, type of wall technology and curtain wall), openings (material and type of windows, type and transparency of glazing), screens in the facade and roof (orientation, type and technological system);
2. Technological performance: energy class of the building, thermal transmittance (of the vertical and horizontal opaque structures, transparent enclosures and glazing), light transmission (internal lighting levels integrated with internal lighting), sound insulation (of the facade and noise level of the floor decking), mechanical ventilation (air exchanges per hour);
3. Intelligence: building automation and building management (field devices installed on the building envelope, methods of connecting to the network and exchanging information with systems,

automation areas and supervision and management areas), photovoltaic and renewable energy (orientation, tilt and integration of the installation with the facade or roof of the building), communication (communication capacity and impact of the architectural design);

4. Safety: safety glass (type and Uni or CE marking), intrusion control systems applied to the building envelope;
5. Maintenance: regular (frequency and systems applied to the building envelope), systems and maintenance equipment (scaffolding, ladders and availability of spare parts on the market).

3.2 Questionnaire for systems builders

The main players of the Building Automation market, the so-called "system builders", represent companies engaged in the integration and/or production of automation systems, specialised in the creation of applications that provide smart features for buildings [6].

These are large companies that are distinguished by extensive experience in the installation of equipment, components in general and the related network infrastructure needed to create BAS (Building Automation System) and BMS (Building Management System) applications.

Among the main players, representative of the international market in terms of dissemination of systems installed, you can find: ABB, Cisco Systems, Honeywell, Schneider Electric and Siemens. These operators constitute the sample analysed, to whom the questionnaire was submitted. The questionnaire was organised in order to collect information on:

1. the types of detection or installations/applications that are usually related to the building envelope;
2. the technologies adopted for communication between the sensors in the field as well as between the sensors and the control centre (sensors applied in the internal areas of the building, on the internal part of the building envelope, in the cavity, etc.);
3. technologically available applications adopted only partially or not adopted by the market (highlighting the main issues/barriers).

4. Market mapping

The research identified a representative sample of recently constructed buildings in the tertiary sector, considered *best practices* and/or significant to highlight the trends of the construction and real estate industry. The selected sample included both initiatives in the design phase and already completed projects.

4.1 The Energy Park Technology Campus

Figure 3: The main facade of the Energy Park technology campus.

Location	Vimercate – Milano (Italy)	**Type of intrervention**	New construction
Intended use	Tertiary, laboratories, IT rooms, auditorium, test rooms	**Client**	Segro
Year	2009	**Designer**	Garretti Associati srl
Area	11.500 mq	**Building envelope**	Teleya

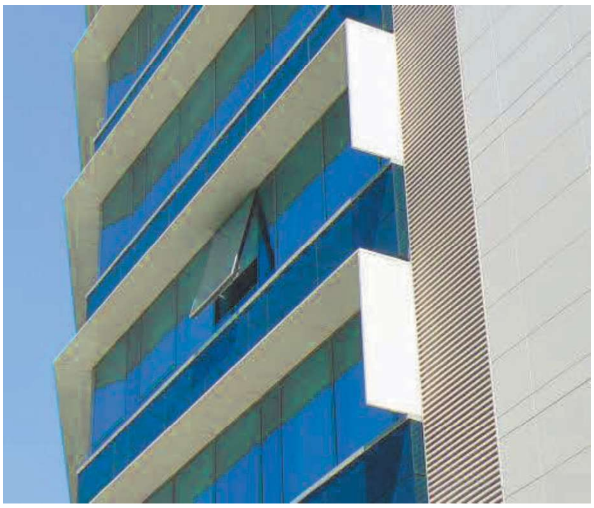
Table 1: The design data of Energy Park technology campus.

The building envelope is characterised by a ventilated façade, externally clad with a corrugated steel sheet with partially perforated Alzunic finish. These are prefabricated, reinforced concrete panels, assembled dry. Internally, the building envelope is clad with CNC cut Scots pine wood with impregnation carried out with a technology capable of ensuring great durability. The wood source is certified PEFC (*Programme for the Endorsement of Forest Certification schemes*). The building envelope is designed with characteristics adapted to contain the costs and to be made in very short time.

Two types of sensors are applied to the building envelope:

- bioclimatic sensors attached to the external blinds and managed by software that allows them to respond to climatic conditions;
- radiation sensors able to exchange information with the internal lighting system so as to ensure the control of the amount of light emitted as a function of the penetrating light.

4.2 The building of Via Vespucci in Milan



Figures 4-5: On the left, the ventilated façade and structural curtain wall; on the right, a detail of the ventilated facade.

Location	Milano (Italy)	**Type of intrervention**	Retraining
Intended use	Tertiary and retail	**Developer**	Generali Properties Asset Management
Year	2008	**Designer**	General Planning
Area	7.214 mq	**Building envelope**	CNS S.p.A.

Table 2: The design data of the building in via Vespucci.

The project involves the construction of different types of building envelope considering the orientation of the building: a continuous glass façade composed of aluminium mullions and transoms and fixed, opening cells that protrude, a ribbon window facade characterised by two-tone bands and shading slats and a ventilated facade. Transparent surfaces are made with low-emissivity selective glazing with a maximum thermal transmittance of 1.1 W/m^{2}K. The transmittance including the frames is equal to about 1.3 W/m^{2}K. The matt surfaces are made with sandwich panels 5 cm thick with a smooth, pre-painted finish and by an additional layer of high density insulation 8 cm thick. The total thickness is 13 cm, with an overall thermal transmittance value of about 0.29 W/m^{2}K. The insulating package of the walls and of the roofs is made with a thermal insulating panel of expanded volcanic rock (perlite) 7 cm thick and by asphalt binder; the overall thermal transmittance of the shell is about 0, 40 W/m^{2}K, 7 cm thick.

No specific BMS solutions were adopted with the exception of internal temperature sensors applied to the building envelope.

4.3 Perseo Expo District


Figures 6-7: Views of the Perseo Expo District building.

Location	Pero – Milano (Italy)	**Type of intrervention**	New construction
Intended use	Tertiary	**Developer**	Galotti S.p.A.
Year	2010	**Designer**	Goring and Straja
Area	10.300 mq	**Installations**	BRE engineering / Studio Massacesi - Europrogetti

Table 3: The design data of Perseo Expo District.

The building envelope consists of a ventilated double skin façade, characterised by metal frames with high thermal break and solar control glazing of the low-emissivity type with high acoustic performance.

Solar control is guaranteed both by the presence of blinds placed inside the facade, and by a shading structure, of the fixed type, placed on the front. In addition to the opening windows, natural ventilation is ensured by two particular architectural elements: the entrance halls and a bridge connecting the two buildings that make up the construction. The first, protected from excessive sunlight, are equipped with an automatic opening mechanism that, during the summer nights, allows to evacuate accumulated heat. The bridge is also protected by a *brise soleil* roof, and has a closing system made of opening glass panels, which regulates the entry in the courtyard of the breeze coming from the southwest. The building is also equipped with an integrated photovoltaic system, installed with an inclination of 60° and oriented to the southeast.

The solutions applied to the building envelope allowed to classify the intervention in energy class A. The devices installed (external and internal temperature probes (placed in the cavity, sensors for internal and external relative humidity, radiation, fire, motion and camera sensors) send and receive data to the HVCA plant and to the screening system using a mixed network, wired and wireless.

The supervision areas involving the exchange of information gathered by the sensors concern the energy management, access control and occupancy detection, intrusion and CCTV system, fire detection and extinguishing system.

4.4 Blend building

Figures 8-9-10: some images of the double skin building envelope of the Blend Building.

Location	Milano (Italy)	**Type of intrervention**	Retraining
Intended use	Tertiary	**Property**	Pronus S.p.A./Generali Properties S.p.A.
Year	2009	**Designer**	Studio “5+1AA Alfonso Femia Gianluca Peluffo”
Area	16.064 mq	**Installations**	AI Engineering, AI Studio

Table 4: The design data of Blend building.

The new building envelope is characterised by a ventilated double skin facade consisting entirely of transparent glass: an internal one of the low emissivity and insulating kind, and a single outer skin, partially selective. Interposed between the two layers there is a solar screen consisting of a micro perforated roller blind.

The whole is designed as a real *dynamic system* where natural ventilation and screening management are of great importance. The natural ventilation caused by the "chimney" effect that is created in the cavity can be activated or stopped by opening or closing the air vents placed at different heights. This movement is automatic and is controlled by a central system which is based on the analysis of appropriate sensors, distributed as follows:

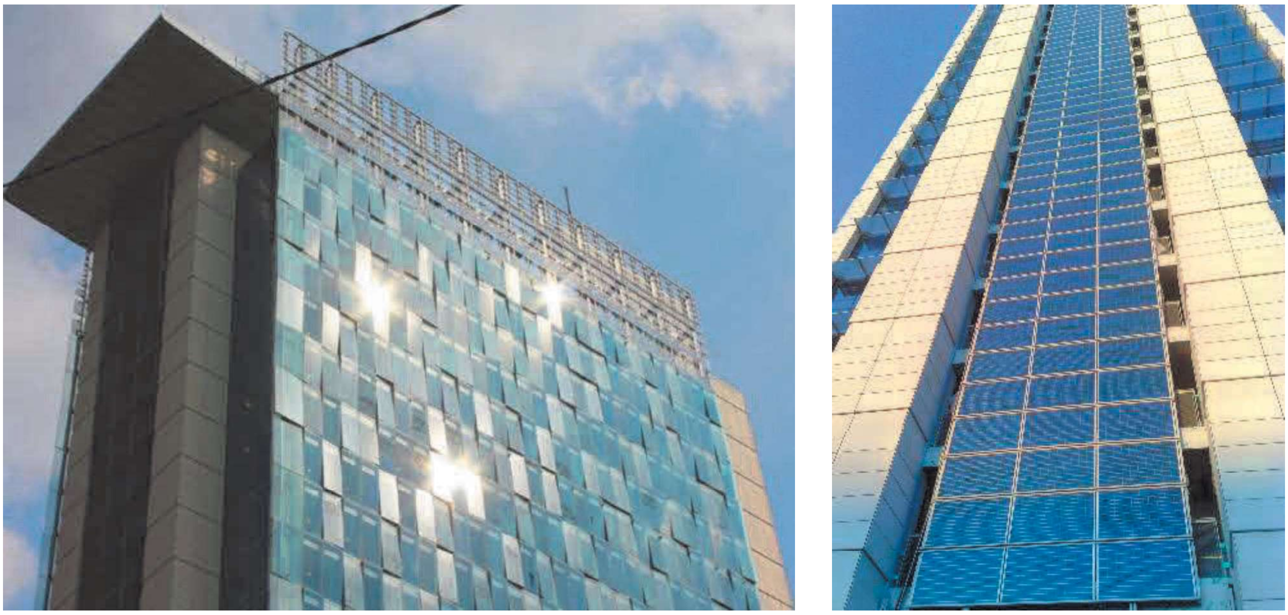
- cavity thermocouples: placed in the cavity at 3 different levels, measure the air temperature at the 3 levels;

- external and internal thermocouples: measuring both external and internal temperatures;

The data measured by the sensors are collected by a central control system that, by integrating the analysis of the operation state of heating or cooling systems, determines the opening or closing of the air vents. Even the motion of the screening system, of the mobile and filtering type, can be managed by a software system or directly by users: each command controls 4 adjacent modules corresponding to different working environments.

The equipment installed (external temperature sensors, internal temperature sensors, fire and motion sensors), sends and receives data to the HVAC system and to the screening system through a wired network. This makes it possible to exchange information with the various supervisory areas present: Energy Management (temperature control, air conditioning, fluid distribution, and accounting) and environment control systems.

4.5 Garibaldi Tower



Figures 11-12: Some images of the Garibaldi Tower building envelope.

Location	Milano (Italy)	**Developer**	Beni Stabili S.p.A.
Intended use	Tertiary	**Designer**	Progetto CMR
Year	2007	**Building envelope**	Permasteelisa
Type of intrervention	Project of conservative improvement	**BMS**	Schneider

Table 5: The design data of Garibaldi Tower.

The building, featuring an interactive ventilated façade divided for each exposure facing, works as a system that evaluates the overall hydrothermal and natural lighting availability of the building. The BMS system, connected to the facade and divided by cells, is able to: check the internal temperature, operate forced ventilation and adjust the inclination of the inner slats of the blinds according to the inclination of solar radiation.

The following automation systems were applied to the building envelope (connected to the network via wired system): external temperature sensors placed inside the wall cavity, outdoor and indoor relative humidity sensors, anemometers (for solar chimney), fire sensors, CCTV cameras and electric actuators for the automatic opening of doors and windows.

5. The return data

5.1 The results of the research aimed at designers

The interviews and case studies examined showed a very even situation in the Italian market. The wall solutions that are adopted more frequently refer, in particular, to energy saving and the use of renewable energies. The emphasis is, in fact, to comply with the limits imposed by current legislation in relation to transmittance limits.

Modern building envelopes are created using technologies such as: ventilated walls, special glazing (selective, low-emissivity, solar control, etc.), curtain walls with thermal break, special materials, screening, etc.

But *building automation* sensors and systems applied to the building envelope that interact with the building are very few. The interviews conducted showed that currently, the technology is at a very advanced stage and allows to create any type of sensor but, in contrast, customers still do not require this type of product. In the cases analysed, more than 50% are equipped with a home automation system.

Great attention is also paid to the attractiveness that the building can guarantee through its image. Nevertheless, systems such as media facades, backlighting, rear projection, etc., have not yet had a large spread in Italy.

5.2 The results of the research aimed at system builders

The different people involved, interviewed directly, expressed unique considerations quite similar to each other. For this reason, we consider it is more useful to explain the results in a comprehensive manner. Based on what was found during the interviews, the "system builders" category shows:

- a "passive-reactive" attitude in the identification of innovative solutions related to the building envelope;
- an interest to speak with manufacturers/installers of building envelopes and implement strategic partnerships.

These operators say they are basically ready to support any kind of request/requirement related to intelligent applications for the building envelope. Their attitude, which can be termed "passive-reactive", is derived from the wide range of technological solutions offered by the market for the detection of those variables (sensors) useful for achieving temperature and humidity well-being inside buildings, as well as rationalising costs and thus saving energy (BAS - Building Automation System and BMS - Building Management System).

The transmission of data collected from sensors in the field and, therefore, also from installations concerning the building envelope, can give rise to integrated functions and automations attributable to any plant located inside the property. Concerning specific smart/home automation solutions regarding installations on the building envelope, which according to the sample may have a greater market penetration, we highlight:

- wireless communication and solar powered external sensors;
- climate wall;
- dynamic lighting management in keeping with the natural light intake and solar screens.

Regarding installations and innovative automation/building envelope inspection features, the sample does not make any distinction between the methods of approach adopted in Italy and those adopted internationally.

Although other contexts may be more receptive because of a greater spread of "intelligent" buildings on their territory and, therefore, a market readier to accommodate the typical logic of building automation, there are no particular cultural barriers characterising our national context. On the other hand it should be added that BAS and BMS applications are especially for large "*buildings*" or complex buildings that are very often attributable to major international operators who tend to express the same needs, regardless of the reference territorial context.

5.3 The role of the building envelope designers

Discussing with the operators involved in the project and, in particular, in the development of building envelope systems, has highlighted the increasingly common role of professional figures dedicated in a specialised way to facade systems, the "building envelope designers".

They are figures, usually found in specialised engineering companies, whose specific expertise addresses the solution of issues related to facade systems, not solved by the architectural project or by the component suppliers and/or by the construction company. As verified in the qualitative survey conducted for the research, the project designer does not always develop a project with the level of detail that allows its creation; for this reason, the need for a study that interprets the architectural design and assists the company responsible for providing the façade is quite common.

5.4 The relationship between developer, investor and end user

Adopting "intelligent solutions", or home automation systems that enable the building envelope to react actively to external signals tailoring its services to the different conditions, involves a commitment to incremental spending compared to traditional solutions. In fact, as a result of the discussions carried out, this cost delta does not seem to be easily identifiable nor does there seem to be a benchmark reference. Basically, it is not clear what the % share of the total construction cost is. What is evident is a different spending propensity, for the superior performance by the envelope-building-plant system, by the various entities that constitute the customers.

The construction company, committed by contract to the construction of the building, earns its margins from the difference between construction costs and revenues from the sale of the building. For these reasons, generally the firm is oriented to reduce the construction costs to maximise its profit. This kind of customer does not appear to have any specific interest in intelligent systems or particular performance attributable to the façade systems.

Investors committed institutionally and/or by company bylaws to invest capital raised in the market or by reference shareholders in construction/development operations for the sale or, more frequently, for income generation (lease to third parties). In this case, there is a greater propensity to study solutions and systems with performance that allows to increases the rent or make the most attractive buildings, meeting the request predominantly of medium to large companies. Investors who may significantly have more demand for intelligent systems, are the real estate investment funds engaged in development projects or upgrading of their assets.

Finally, there is the end user represented by companies that require buildings for direct use. In this case, there is a propensity to greater expenditure in view of benefits or more demonstrable performance (reduction of fuel consumption, increase of the comfort conditions, etc.).

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