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Monitoring System Analysis Used for Evaluating the Building's Envelope Energy Performance Through Estimation of its Heat Lost Coefficient

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Abstract: The present article is dealing with the state of question about building-energy monitoring systems used for data collection to estimate the Heat Lost Coefficient (HLC) with existing methods and so determinate buildings' Envelope Energy Performance (EEP). In addition, the data requirements of HLC estimation methods are related with commonly used methods for fault detection, calibration and supervision of energy monitoring systems in buildings. Based on an extended review of experimental tests since 1978, a qualitative and quantitative analysis of Monitoring and Controlling System (MCS) specifications has been carried out. Although most actual Buildings Automation Systems (BAS) may measure the required parameters, further research is still needed to ensure that these data are accurate enough to rigorously apply the HLC estimation methods.

Keywords: Building Energy Monitoring System, Heat Lost Coefficient (HLC), Fault Sensor.

1. Introduction

This headland shows an introduction about energy consumption in Europe, the role of HLC estimation to know the Energy Performance of Buildings (EPB), the monitoring systems used for this estimation and the role of fault detection in building energy monitoring systems.

The objective of this section is to explain the importance of estimating the Heat Lost Coefficient (HLC) and Envelope Energy Performance (EEP) to know the Energy Efficiency of Buildings (EEB) in order to generate Energy Performance Certificates (EPCs), as a tool to determine the discrepancies between performances at design and operation phases. Actual envelope energy performance, actual energy equipment performances and user's behavior are the three main reasons for a building to consume differently from the design conditions. The European regulations mark a line to follow to ensure transparent and consistent EPCs, through reliable methodologies to estimate the EEP of buildings. These methodologies used to HLC estimation in turn need to be fed with physical variables collected and processed by a Monitoring and Controlling System (MCS), which is composed of elements with the necessary precision to generate reliable EPCs. Likewise, MCS needs detecting and minimizing faults in order to guarantee more accuracy in results by minimizing the error in calculations. Currently, existing smart buildings are monitored and controlled with various building systems (e.g. HVAC, heating, light systems), but do not have integrated a MCS as currently used in experimental tests to estimate EEP and HLC.

1.1. *Energy consumption of buildings in Europe*

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The potential for energy demand growth from connected devices in buildings, whether they are smart or not, is already noticeable in many Europe Union (EU) markets[1]. In the International Energy Agency (IEA) Central Scenario, 50% of household electricity demand for appliances by 2040 is expected to come from connected devices, presenting opportunities for smart demand response, but also increasing the need for standby power. 'Improving the operational efficiency of buildings by using real-time data could lower total energy consumption between 2017 and 2040 by as much as 10% compared with the Central Scenario, assuming limited rebound effects in consumer energy demand [2].

Rise the Energy Efficiency of Buildings (EEB) can generate economic, social and environmental benefits, and improve the building performing, providing better comfort and wellbeing levels to users, as their health due to indoor climate improvements. Besides it is necessary to reduce buildings energy consumption, which represents approximately 40% of energy consumption in Europe, as well as to reduce CO_2 emissions that represents 36% [3].

The European Council, in March 2007, emphasized the need to increase building energy efficiency in the Europe Union. Which considers their saving energy is more than by 20%, thus wants to reduce in this ratio their energy consumption in 2020 through the "Action plan for energy efficiency: realizing the potential"[4]. The reduction of 20% is a matter of urgency of the action plan, and equivalent to around 390 Mtoe, being this energy saving has been supported by the Green Paper on energy efficiency [5].

Approximately 35% of buildings in the EU are over 50 years old. Of this percentage only are renewed around 0.4% - 1.2% (depending on the country). This implies that a greater renovation of existing buildings can generate significant energy savings through the reduction of 5% - 6% of the total EU's energy consumption and 5% by reducing CO_2 emissions [6] . The "Action plan for energy efficiency: realizing the potential" calls to all regional and local authorities to develop energy efficiency plans and transpose into national legislation the directives on the energy performance of buildings, due improve the energy efficiency of buildings [7].

The EU commission gives support for energy efficiency to all Member States through operational programs settings out the implementation of the Structural Founds. The studies and research on energy efficiency of buildings have been growing and there are many studies about building retrofits and new building design to reduce energy consumption and get more energy efficient buildings [7].

The European Commission presented on 30 November 2016 a proposal for a modest review of Directive 2010/31 / EU on EEB [11]. Part of the Package of measures in Clean Energy aims to meet the objectives of energy and climate of the EU 2030, together with the Directive on Energy Efficiency of Buildings (EPBD) [12] which aimed at achieving the EU's energy efficiency objectives, that are also addressed in the Energy Efficiency Directive (EED) [13]. The proposed revision of the EED (part of the Clean Energy Package) establishes a greater number of energy efficiency measures by 2030, in order for Member States to achieve at least 20% improvements in energy efficiency by 2020 [14].

Energy efficiency and renewable energy technologies were the leading areas of Research, Development and Design (RD&D) investment of European Commission, reaching significant shares (24% and 26% respectively) of the total energy RD&D budget in 2015. RD&D for fossil fuels had the smallest share, accounting for 6% of the total budget in 2015 [15], and everything

[1] According to a study carried out by Statistics the control and connectivity segment in smart homes is expected to amount to 43.7m by 2022 [1].

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indicates that this investment will be maintained in order to carry out the package of measures in clean energy in order to meet the goals of 2030.

1.2. *Heat Loss Coefficient's calculus to determine the building performance and the energy consumption calculation by the users*

The Energy Performance of Buildings Directive 2010/31/EU [11] in order to guarantee uniform conditions for the application of this Directive, proposes grant powers to the European Union for rating the smart readiness of buildings. These powers must be exercised in accordance with Regulation (EU) No 182/2011 of the European Parliament and of the Council [16]. This regulation specifies the need to have a smartness indicator that is used to measure the capacity of buildings to use Information and Communication Technologies (ICT) and electronic systems, in order to optimize the operation of the building and to be able to interact with the network. The smartness indicator will create awareness among the owners of buildings and their occupants about the value that lies behind the automation of buildings and the electronic monitoring of technical building systems, increasing the confidence of the occupants in the ability to obtain a real savings when introducing new improved features in their dwellings. The use of the plan to qualify the good design of the buildings must be voluntary for the Member States.

The mentioned proposal, specify also the importance and the effectivity of building automation and electronic monitoring of technical building systems in the technical inspections. Being used to inspections in large non-residential and multifamily buildings of a sufficient size that allow a payback of less than three years, in which the installation of such equipment should be considered as the most cost-effective alternative.

At the same way, talks about the importance of comparing EPCs issued before and after renewal. Which must use transparent method provided by the installer of certification or qualification level, to measure the performance of the equipment or material used for the renovation; and thus guarantee the best use in the renovation of buildings, relating the renovation quality with financial measures and energy efficiency. To meet the objectives of energy efficiency policy for buildings, the transparency of EPCs should be improved by ensuring that all necessary variables for calculations, for both certification and minimum energy performance requirements, are set out and applied consistently. Member States should put in place adequate measures to ensure, for example, that the performance of installed, replaced or updated technical building systems for space heating, air conditioning or water heating, is documented in view of building certification and compliance checking.

A report of the EPBD Compliance Study [17, 18] remarks the importance of monitoring, control and quality assurance systems as an essential part of assessing the compliance rates that requires validation of the legitimacy and confidence in source data used when reporting compliance.

Directive 2010/31/EU [3, 7] makes emphasis about the methodology employed for calculating energy performance should be based not only on the season in which heating is required, but should cover the annual energy performance of a building. That methodology should take into account existing European standards.

According the Article 3 of the EPBD [3], the EU Member must estimate the building's energy performance using a specific methodology, as minimum using standardized conditions specified by national regulations. Taking into account the HLC is one of the Key Performance Indicators (KPI) [19] of energy performance.

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To estimate the Heat Loss Coefficient (HLC) is necessary collect physical variable data of in-use building or an unoccupied building depending of calculus methodology employed to estimate the HLC. The sensors necessaries should measure among others the temperature, heating, ventilating, solar radiation, energy consumption, etc. [19, 20] to improve and demonstrate the energy efficiency of buildings' envelope, the in-use buildings monitoring will be grow in the next years to collect the physical variable data necessaries to obtain the buildings envelope thermal characteristics.

The thermal performance of whole buildings envelope is most often quantified by the heat-transfer coefficient (HTC). 'HTC' is interchangeable with a second term, the heat loss coefficient (HLC), which has often been used when reporting co-heating results. 'HTC' has been adopted as a standard term in line with the naming convention used in ISO 52016-1:2017 [21], the international standard method for calculating the energy performance of building, which cancels the standard ISO 13790:2008 [22]. The HTC is a useful metric that describes the total, time-averaged, rate of heat transfer (in watts) from a building per-degree-Kelvin difference between indoor and outdoor air temperatures. Each building can be assumed to have a constant HTC, a value that is estimated as a metric in building energy models such as Standard Assessment Procedure[2] (SAP). By measuring the HTC, the thermal performance of the whole building envelope, as built, can be directly compared with the estimated performance, independent of occupant behavior and weather conditions.

1.3. The monitoring systems used to estimate HLC to determine the Building Envelope Thermal Performance.

Given the importance of the requirement for measure the building performance, the paper reviews the monitoring systems used to know the energy efficiency level of buildings through the physical data collected by sensors, to estimate the energy performance using specific methodologies, which in future will guarantee transparent EPCs for minimum energy performances. For this, the article will focus the study in the energy monitoring used in projects used to estimate the HLC with two methods, the averaging methods [19] and regression methods similar to the Co-Heating method [24, 25] along with other methods used to calculate the Building Envelope Performance (BEP).

The latest report Digitalization & Energy [15] of IEA in 2017, where there is a greater potential for energy savings is in heating, cooling and lighting, since the set of these in 2015 accounted for more than 60% of the total demand for final energy in buildings. The report also highlights that sensors, intelligent controls and the use of connected devices consume energy to maintain connectivity, even when they are in standby mode. Which are necessaries to improve the energy performance of the building, for example, the use of intelligent thermostats improves the management of heating and cooling loads, allowing an improved and even remote control of the temperatures throughout the building.

Without automated monitoring and fault detection, and the sensors and controls on which they rely, performance can degrade. The number and range of types of sensors installed in commercial buildings today is inadequate to provide sufficient automated (or even visual) monitoring [26].

The characterization of the in-use building energy envelope and its systems, needs a monitoring system that provide a real data, being necessary in turn to have a minimum sensor set to obtain a correct characterization. The data collected from the sensor set, shall be analyzed with different

[2] "SAP is the United Kingdom (UK) governments Standard Assessment Procedure to calculate a buildings energy efficiency and carbon emissions" [23].

and robust methodologies due to the large amount of data obtained from the building monitoring systems.

Currently some energy monitoring systems are integer in domotic in order to give information of energy consumption and realize the control of user comfort parameters. Still there is no evidence of an energy monitoring system with a minimum sensor set specific to characterize the in-use building energy envelop integer in a domotic system, in order to know the real energy efficiency of buildings' envelope after the construction or retrofit of a building.

1.4. Fault detection and calibration in building monitoring systems

Buildings may have operational problems due to problems associated with degraded equipment, failed sensors, incorrect installation, poor maintenance and improperly implemented controls. Currently, most problems related to building systems are detected through complaints from occupants or alarms provided by Building Automation Systems (BAS). Detection and diagnosis can be performed automatically and integrally by integrating the experience required to detect and diagnose operational problems, in software tools that take advantage of existing sensors and control systems. These tools are not designed to replace the people who operate the construction systems, but to help them improve the functioning of those systems. The automatic start-up and diagnosis technologies for systems and construction equipment are expected to be tools to reduce and act on problems and improve the functioning of the building with the automatic and continuous detection of performance problems and maintenance requirements so that be communicated to the building operators, who can perform the necessary corrective actions when necessary [26].

Due to the large amount of data collected from sensor sets, is necessary to address which calibration system and methodologies are applied in the building energy monitoring systems, building systems and know the sensor set necessary to characterize the energy performance of in-use buildings' envelope. The literature relative of fault detection and calibration in building monitoring, is focused on all building systems like fan coils, Heating, Ventilation and Air Conditioning systems (HVAC), heat pump, air conditioners, commercial refrigerators, lightings, water heaters, chillers and cooling towers, Air Handling Unit (AHUs) and Variable Air Volume (VAV) boxes. Of all the works studied has not been found so far, a specific methodology applied to the entire sensor of a building monitoring system and domotic systems, just there are methods applied to one subsystem of this one, the building systems mentioned.

One of the main difficult to calibrate and detect the fault in a building monitoring system, is the complex and robust systems, like the multiple sensors used with its corresponding data collected, besides the complex software and programming system are necessaries to process and controlling the monitoring system. This paper review different methods to calibrate and detect the faults in order to analyses the drawback of apply the fault detection methods in a robust system, with robust data collected from a monitoring system, which is used to characterize the building envelop, in case of being integrated in building automation.

2. Materials and Methods

This section start with a review about building automation, communication protocols, sensors and the fault detection methods most used in building control systems. This first review helps to give perspective on monitoring to controlling system necessary in buildings automation, systems currently used in experimental tests to analyze and estimate the HCL and BEP. In order to identify and analyze the MCSs implemented in current research projects, then it will be passed to review literature that use experimental tests to estimate the HLC using the average method, Co-Heating method and other methods considered to estimate the BEP. This reviewed literature

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will allow identifying the equipment make up MCSs, which are used to collect and process the physical variables in these experimental tests.

2.1. Building Automation

The Building Control System (BCS), also termed Building Automation System (BAS) or Building Management System (BMS), is control systems composed by hardware and software networks integrated to monitor and control the indoor climatic conditions in building facilities, besides usually they are integrated systems [27].

The Building Automation System (BAS) is installed to monitoring and controlling the heating, cooling, ventilation, air conditioning, lighting, shading, life safety, alarm security systems, and other building systems [28]. The system can be divided into four areas: applications, hardware, communications, and oversights [26]. The BAS is a part of the Intelligent Buildings; where this 'intelligence' implies capturing the current state of the building and its devices through the collecting physical variables and of signal processing to make the appropriate adjustments so that the building inhabitants are increased its marginal utility in terms of comfort and energy cost. Intelligent buildings increase this marginal utility through sensor systems integration, computer automation, information and communication systems, smart home appliance devices, and new materials [29].

Domotic is other term used frequently and made reference to building automation; is defined by S. Millán-Anglés [30] as a scalable set of services integrated into the home and that are provided by systems that can configure one or several internal networks of the habitat and that, in turn, can communicate with networks outside the home. These services make functions related to energy saving, technical management of facilities, information, communication, leisure, accessibility, assistance, comfort, etc.

Georgios Lilis [31], define three hierarchical level of functionality in a BAS. The management level where all information is collected, aggregated and represented for be manage by operator. The automation level includes the entire infrastructure for controlling and applying management of the data or system supervision, in which interacting devices range from the environmental sensors as luminosity, humidity, temperature, presence, etc., to the actuators controlling passive devices and environmental parameters as heating, lighting, access to premises, etc. And finally the field level where belong all the end-devices and field buses which interface the physical world, used in automation of industrial process and buildings, which are limited solely to point-to-point communication within the BAS.

The functions Building Automation and Control Systems (BACS) belong generally to the Heating, Ventilation and Air Conditioning systems (HVAC); Domestic Hot Water (DHW); lighting system control; shading systems control; energy conversion and storage (heating and cooling); onsite power generation; monitoring and data acquisition; communications and security management [32]. Building automation integrates technology in a closed space with intelligent designs, which in turn can be integrated by indoor and outdoor communication networks, wired or wireless, for so that energy management is efficient and includes the air conditioning and boilers control, awnings controls, and electric shutters and electricity management.

The economic and legal restrictions regarding energy consumption and environmentalism define the building energy borders [29]. Being possible the house system optimization through the control system BAS, which help to improve occupants comfort while reducing the electricity consumption and expedite the operation, monitoring and maintenance of buildings [28]. The

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reduction of electricity consumption and improve the occupant comfort make the building an energetically efficient system, which is largely achieved by the interacting with a wide range of sensors that collect physical variables such the temperature, CO_2 concentration, zone airflow, daylight levels, occupancy levels, etc. [26]. Even so, the energy management is conditioned by user behavior and its comfort conditions having into account in the building automation the lighting control, heating and cooling system control.

2.2. *Protocol communication used in a Building Automation.*

Communications play a major role in enabling building-wide controls, the communication protocols let communication between devices and are central in the data transmission to share essential information that allow effective control function. This transmission use physical media through which control information and commands pass between devices trough twisted-pair wiring or wireless devices, have a substantial impact on the installed cost of building controls in building automation systems [26], Table 1 shows others analogies between the wired and wireless communication protocols .

Table 1. Differences between the Wired and Wireless communication protocols [28].

Wired	Wireless
High bandwidth	Low-medium bandwidth
High performance	Higher latency
Robust	Interference
Reliable	Unreliable by nature
Instalation expensive	Instalation cheap
"Unlimited" resources	Low power, memory
Static network	Mobile network
Less security problems	More security problems

Today, building automation systems can be realized using a multitude of different standards. In 2010 IEEE International Symposium on Industrial Electronics, has been remarked that the main building automation protocols by wired are KNX[3] (EN 5 0090, ISO 14543), LonWorks[4] (ANSI / E IA-709, EN 14908), BACnet[5] (American National Standards Institute (ANSI). American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 13 5 - 1995 -7, ISO 16484-5) protocols; and by Wireless KNX-RF, EnOcean[6], standard based on Institute of Electrical and Electronics Engineers (IEEE) 802.15.4, ZigBee[7] [38]. Currently, BACnet, LonWorks, KNX and ZigBee technologies (based on IEEE 802.15.4) have attained considerable weight in the global market, as KNX has a strong presence in the European market [31]. Other technologies frequently

[3] KNX is an international standard (ISO / IEC 14543-3), European (CENELEC EN 50090 and CEN EN 13321-1) and Chinese (GB / T 20965), open for control in both commercial and residential buildings [33].

[4] The LONWork standard is based on the scheme proposed by LON (Local Operating Network). The standard has been ratified by the ANSI organization as an official in 1999 (ANSI / EIA 709.1-A-1999) [34].

[5] BAC net is a Data Communication Protocol for Building Automation and Control Networks. Developed under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published in 1995, the BACnet standard, whose objective is to provide a solution to the systems of automation and control of buildings of different sizes and types [35].

[6] The modules based on EnOcean technology combine micro power converters with very low power electronics. This technology allows wireless communication between wireless sensors without batteries, switches, controllers and gateways. EnOcean is a wireless energy capture technology used in building automation systems, and other industrial applications, transportation, logistics and smart homes [36].

[7] Zigbee specifies a set of high-level wireless communication protocols with low-power digital transmission, based on the IEEE 802.15.4 standard for Wireless Personal Area Networks (WPAN) [37].

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used in BAS are EnOcean, Insteon[8], Modbus[9] and Z-Wave[10]. The low-power wireless communication protocols as EnOcean and Z-Wave are generally used in home automation and industry. Similarly, Insteon is not restricted and gives support for wireless communication and being generally used for home automation but is not limited to this [28]. According to a report from the Superior Council of Scientific Investigations of Spain - CSIC report (2014) [30], the most used communication protocols are Wifi, Ethernet and Bluetooth. As for the control protocols, these are the EIB and KNX. The most used frameworks platforms are Lonworks, Universal Plug and Play (UPnP)[11] and Open Services Gateway Initiative (OSGI)[12].

The gateway-based[13] approach is responsible for several disadvantages, the literature demonstrates designs for multi-protocol devices, since it is a gateway-free solution eliminating the need for specialized gateways for the inter-protocol communication, increasing the potential product range available for each manufacturer and decreasing the installation cost and number of devices needed in building automation [44]. Unfortunately, protocols used in building automation are often not compatible among each other, inter-operation across system boundaries requires special gateway solutions. To counteract these limitations, several middlewares[14] solutions have been developed that allow the communication of adjacent sides so that there is abstraction of the specific details of the provider of the BAS components [46].

Currently there is no intrusion detection and prevention available for the BAS network, which increasingly extend their functionalities and their connection to internet, which significantly increases the exposure of BAS networks to cyber-attacks due to the significant increase in the attack surface. This also increases the interconnection between communication protocols due to the increase in information services and advanced network technologies, with the need for Could Computing[15] and Fog Computing[16] increasingly to provide solutions for the automation of final devices [49].

2.3. *Sensors used in a Building Automation*

The sensor systems in advanced intelligent buildings are required to provide comfort high performance and automation, energy and resource savings and security [29]. In 2010, many

[8] INSTEON is a domotic network technology designed by SmartLabs, Inc. It is designed to allow devices such as switches, thermostats, sensors (movement, heat, smoke etc.) to be connected in a network through the power line, the Radio Frequency (RF) [39].

[9] Modbus is a communications protocol located at level 7 of the OSI Model, based on the master / slave architecture (Remote Terminal Unit (RTU)), or client / server, (Transmission Control Protocol / Internet Protocol (TCP/IP)), designed in 1979 by Modicon for its range of Programmable Logic Controllers (PLCs) . Developed into a de facto standard communications protocol in the industry, it is the one with the greatest availability for the connection of industrial electronic devices [40].

[10] Z-Wave is a wireless communications protocol used mainly for home automation. It is a mesh network that uses low-energy radio waves to communicate from one device to another, allowing wireless control of appliances and other devices [41].

[11] The UPnP architecture allows the interconnection between devices such as personal computers, home appliances, consumer electronics devices and wireless devices. It is a protocol with an open architecture [42].

[12] OSGi began in 1999 as a set of standards for a Java-based service framework that could be managed remotely. OSGi was originally conceived as a gateway to manage smart devices and other Internet-enabled devices in the home [43].

[13] The use of Gateway has several drawbacks. A storage of large mapping tables is required, being a factor that limits the scalability of the BAS, since the effort in configuration and maintenance increases with the translation of all the relevant data points that are incorporated from the appropriate segments. This is a significantly large mapping table to be stored and can be a limiting factor with respect to BAS scalability. In addition having a front door can introduce a single point of failure and a security risk [44].

[14] Middleware is software that allows interaction and communication between various applications or packages of programs, networks, hardware and / or operating systems. The communication hidden the resources heterogeneities o software, operating system, protocols, etc., determining the interoperability between them [45] .

[15] “Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services” [47].

[16] “Fog computing is a paradigm that extends Cloud computing and services to the edge of the network. Similar to Cloud, Fog provides data, compute, storage, and application services to end-users” [48].

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modern buildings automated contained a limited number of wired sensors in control systems such as BACnet or LonWorks, this is mainly because the wired sensors installation need for additional wiring for each sensor, wich is a significant barrier in the wired sensor deployment due increase installation cost. The entrance to the market of low-cost wireless sensors without need wire, has opened opportunities in the market so increase the number of connected sensor in buildings, thus allowing for improved sensing of the different necessary variables for make an automation efficient and effective for improve the comfort user [50].

For a correct control of the interior conditions, a considerable number of sensors is necessary to control the unwanted level by the users and to achieve optimum levels in the use of energy. It is also necessary to use optimal control techniques in the system and throughout the building to achieve levels of performance necessary to ensure that the conditions inside the building are of high quality with a minimum consumption of net energy [26, 28, 29, 51].

Extended literatures especify the use of sensors and meters for control and building performance, where the most installed environmental sensors are the ones measuring temperature, relative humidity (RH), and Carbon Dioxide (CO_2), used to achive an optimal performance of HVAC equipment and maximaze the user comfort [32]. As well the sensor to meter electrical power/current is one of the most important types of sensor employed for monitoring energy efficiency. The Table 2 shows a resume of the main sensors and meters used for control in buildings automation.

Table 2. Sensor and meter data for and performance tracking.

Typology	Sensor measure	International System Unit
Consumption	Total Electricity	Wh, KWh, MWh
	Total energy Consumption (Heating, Cooling, light, devices)	Wh, KWh, MWh
	Total Water Consumption	l, m^3
	Total Fuel Consumption	Wh, KWh, MWh, l, Nm^3,m^3
Weather	Temperature	°C
	Relative humidity	%
	Global Solar Radiation – usually horizontal surface	W/m^2
	Wind Velocity	Km/h
	Wind Direction	(0°- 360°)
Indoor Conditions	Temperature	°C
	Relative Humidity	%
	CO_2 Concentration	ppm
	Light Level	lux
Building Systems	Water circuit temperature (supply and return fluid)	°C
	AHU/HVAC circuit temperature (supply and return fluid)	°C
	AHU/HVAC Relative Humidity	%
	Flows	l/s, m^3/s
	Pressures	KPa, Pa
	Presence sensor's Control	0-100%, 0-1, ON/OFF, 0/1
	CO_2 sensor's Control	0-100%, 0-1, ON/OFF, 0/1
Frequency to Collect Data	High Data Acquisition	s, min, h, day
	Medium Data Acquisition	day, month
	Large Period	year

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In literatures, there is not a specification of monitoring system necessary to estimate the energy performance of building's envelope using a specific methodology according with the Article 3 of the EPBD [3], taking into account the HLC is one of the KPI [19] of energy performance. However, there are many studies carried out to estimate the HLC in order to characterize the building's envelope energy performance, which use monitoring and control systems. The monitoring systems needed to measure the user's behavior and comfort are studied in depth in many literatures through the control of heating, cooling and lighting systems, measuring the electrical consumption of homes and buildings in order to know the energy performance of the users. In next section, will present the monitoring system necessary to estimate the HLC using average methods [19] and Co-Heating methods or similar [24, 25], and will present a review of different monitoring systems used in different studies developed to estimate the HLC.

2.4. *Fault detection, diagnostics, pronostics and calibration in building monitoring systems*

Evaluating uncertainties in a test can lead to comprehension errors due to the absence of knowledge about the "true" value of a measured variable, especially in systematic errors due to the absence of reference between the true value and the measured value. The true value of a measurement can never be known with precision, but when you measure the HTC of the buildings, it varies in an unknown way and is difficult to predict, this makes it difficult to assess the uncertainty of the measurements [52]. Some authors have studied the uncertainty in the calculation of the HLC as is the case of Stamp S. [53] that to evaluate the uncertainties in the measurements outdoors, in situ, due to the presence and the treatment of the solar gains. Where, for example, the uncertainties related to solar gains are explored from the results of field tests and simulated Co-Heating tests.

Sensor errors greatly affect the performance of control, diagnosis, and optimization systems within building energy systems, negatively affecting energy efficiency, the calibrated measurements improve the accuracy of energy performance analysis for a building energy system (up to 17.82%) [54]. It is reported the exponential increase of the number of maintenance requests for building energy systems in the past decades, due an increase in building operational faults [55]. Typical operational faults may come from improper installation, equipment degradation, sensor offset or failures, or control logic problems; which can be join into several categories such as: control fault, sensor offset, equipment performance degradation, fouling fault, stuck fault and others [56].

Table 3 shows the impact sensor errors in a monitoring system, which reflect the need to implement and integer in all building automation system tool to detect, predict, diagnose and calibrate the sensor and monitoring systems in an integral way.

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Table 3. Examples of impacts produced by sensor errors in some study cases.

Reference	Error and fault analyzed	Impact
Rongpeng Zhang, Tianzhen Hong [57]	Outdoor air temperature sensor errors and thermostat errors on energy consumption	Increase of cooling energy consumption in 0.8%-13.6%, cooling and heating energy consumption increase in 19.07-34.24%.
Joachim Verhelst, Geert Van Ham [58]	HVAC performance under the faults sensors and actuators in a concrete core activated office building.	Economic impact from +7% to +1000% due a simultaneous sensor and actuator faults (realistic, randomly distributed and no correlative.)
Joachim Verhelst, Geert Van Ham [59]	Identify thirteen key faults based on literature review, developing bottom-up energy impact range.	Increase of 4% to 18% the energy annual consumption of the sum of commercial building HVAC, lighting, and refrigeration energy consumption and is consistent with the typical range of energy waste reported in building commissioning studies.
Kao JY, Pierce E. [60]	Simulation of error effects in the sensors of automatic controls for HVAC systems, in an office building of lightweight construction.	In annual building-energy requirements, increase of 30% to 50% attributable to an air handling system.
Woohyun Kim [61]	Fault detection and Diagnosis for Air Conditioners and Heat Pumps Based On Virtual Sensors: The refrigerant undercharging and its cooling capacity.	Reduction approximate of 20% cooling capacity and 15% energy efficiency if the refrigerant undercharging in the range of 25%.

Automated Fault Detection and Diagnosis (AFDD) is defined as an area of investigation concerned with automating the processes of detecting faults [62], where faulty operation, degraded performance, and broken components in a physical system are detected and understood. AFDD tools are based on algorithms that process data to determine if the source of the data is experiencing an error. The tool can be passive if the operation of the equipment / system is analyzed without modifying any reference point or control outputs, or active, making the changes automatically to produce or simulate operating conditions of a wider range of conditions that could not be modified for some time in a normal operation [26]. The impact of the failures allows determining the priority repairs, directly affecting the reduction of energy and costs, in a greater comfort and useful life of the equipment, and in the reduction of service costs. The severity of the failure and its impact on energy consumption is essential to prioritize repairs. However, assessing the failure or evaluating the impact (energy and cost) is one of the main steps in the AFDD process, but determining the severity of the failure is difficult because in many cases the information necessary to perform the evaluation is not readily available [62].

The sensors and controls performance can degrade without automated monitoring and fault detection. The number and range of types of sensors installed in buildings today is inadequate to provide sufficient automated (or even visual) monitoring. Performance monitoring, automated fault detection and diagnosis, commissioning, optimal control and the use of development environments, design tools and trainers are complementary technologies, with strong potential to realize significant energy savings and other performance improvements in commercial buildings, including existing buildings [26]. All sensor systems are facing a noticeable upward trend in performance requirements for maintenance, downtime, reliability, fault tolerance, fault recovery, and adaptability [29].

The main fault detection and calibration methodologies are specially on building systems like fan coils, HVAC, heat pump, air conditioners, commercial refrigerators, lightings, water heater,

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chillers and cooling towers, AHUs and VAV boxes [62]. In which the potential HVAC operational faults in a typical VAV system in a central plant.

The AFDD methods can be classified in quantitative model-based, qualitative model-based and process history-based [63, 64] (Figure 1). The Process History-Based is the most used when the theoretical model of system behavior is inappropriate to explain its behavior or is not easy create the model, in this AFDD method the Black Box is the most used because of its simplicity. The Qualitative Model-Based (Rule Based) is the second most used AFDD method. The Quantitative Model-Based needs a precise mathematical model of system behavior and reliable sensors for acquisition data, being the most complex and the least popular; it is more used for industrial than building landscape. There are AFDD methods combined these three methods, used in order to improve the efficiency of individual methods and detect failures simultaneously (e.g. Rule-Based combined with statistical methods to reduce the noise, disturbances and uncertainty of monitoring) [62].

AFDD can be integrated into an automatic start-up process. Start-up (new buildings) and commissioning (existing buildings) involve functional tests carried out to determine if a device or system is working correctly. In the commissioning process, the proper functioning of the equipment is verified by observing a series of functional tests, but it is not guaranteed that the equipment can continue to function properly. Only continuous monitoring of the state of the equipment and its performance can guarantee continuous operation. The AFDD system constantly monitors the equipment and identifies failures and loss of performance, being a fundamental system in the commissioning and commissioning of buildings. However, the intervention of the human operator or the repair technician is essential to complete the start-up cycle, but without the automated monitoring system continuously, many problems may not be detected for days, weeks, months or even years [26].

All studies on fault detection and calibration of monitoring systems reviewed, did not apply AFDD methodologies in the energy monitoring system to characterize the building envelope and to know the energy efficiency of in-use buildings' envelope through the HLC estimation. Currently, the methods lack a holistic approach to predict the global impacts of faults at the building level, an approach that adequately addresses the coupling between various operational components, the synchronized effect between simultaneous faults and the dynamic nature of the failure severity [62].

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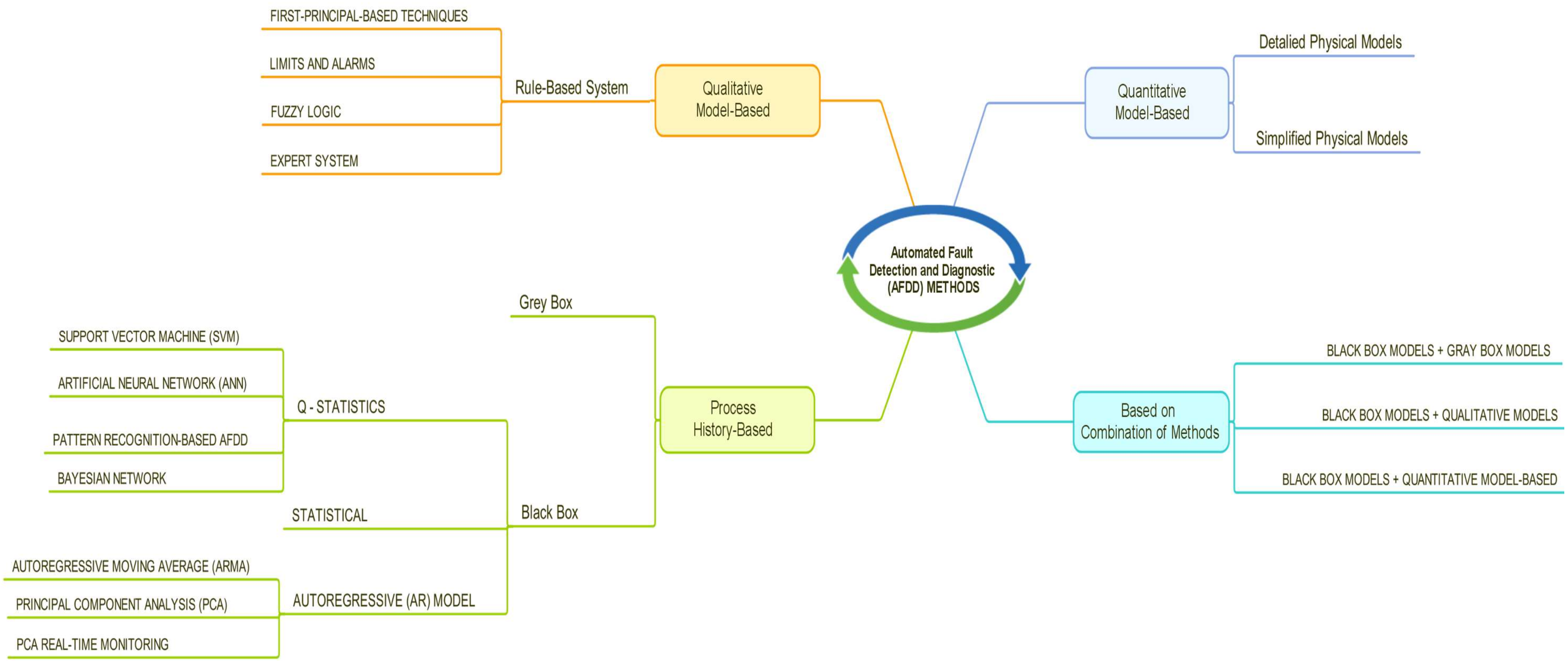

Figure 1. Classification scheme for AFDD methods [64].

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2.5. Monitoring systems use to estimate the Heat Loss Coefficient (HLC) using the average method and Co-Heating method.

To guarantee transparent EPCs for minimum energy performances, it is necessary estimate the energy performance using specific methodologies to know the energy efficiency level of buildings, for which it must collect physical data from sensors of a monitoring system. This section will focus on study of energy monitoring used in projects to estimate the Heat Lost Coefficient (HLC) with two methods, the averaging methods [19] and Co-Heating method or similar [24, 25].

2.5.1. Methods with its references and the main physical variables to carry out in the different methods:

The monitoring requirements of average method and Co-Heating methods will be analyzed showing the main physical variables used and doing a review of the monitoring used in different projects published to estimate the HLC.

Corrected Average Method: [19] proposes an Average Method and a Corrected Average Method, with similarities to the ISO 9869 standard, to estimate the Heat Loss Coefficient (HLC) of the whole building. The method take in to account *k* observation of all heat gains inside building (heating system and all the other internal gains, excluding solar radiation) represented by the (Q + K) and the solar gains (S_aH_{sol}) (equation (1) in specific periods where:

- There is very low solar radiation and is possible to roughly estimate the building solar heat gains. To minimize the uncertainty of roughly estimating the solar gains, the solar gains should be less than a 10% compared to the sum of all the rest heat gains inside the building (Q + K).
- The interior to exterior average temperature difference during the selected testing period should be higher than 15ºC and never less than 10ºC. This buildings' average temperature must be the same at the starting and ending times of the method to make the effect of the change in internal energy of the buildings negligible.

$$HLC_{N,air-to-air} = \frac{\sum_{k=1}^{N}\left(Q_k + K_k + S_a H_{sol,k}\right)}{\sum_{k=1}^{N}\left(T_{i,k} - T_{o,k}\right)} \quad (1)$$

Where:

$HLC_{N,air-to-air}$ [kW/ºC]: air to air Heat Loss Coefficient of the building envelope. HLC considers both losses due to transmission and losses due to infiltrations and/or ventilation.
Q [kW]: all heating and ventilating systems energy inputs inside the building.
K [kW]: all the other heat gains inside the building (illumination, all other electrical devices consumption and heat gains due to people, solar gains and Q not included).
Ti [C]: Indoor air temperature.
To [C]: Outdoor air temperature.
S_a [m²]: Solar aperture.
H_{sol} [W/m²]: Horizontal global solar radiation.
k: Index observations for the period consisting in N measurements of all variables.

To solve this estimation, the physical variables are obtained from four different types of sensors showing in Table 4.

Table 4. Physical variables measured in the Corrected Average Method.

Typology	Sensor measure	International System Unit
Energy Consumption	Total electricity consumed whiting the buildings envelope	Wh, KWh, MWh
	Total energy supplied by the Heating	Wh, KWh, MWh
Weather	Outdoor temperature	°C
	Horizontal global solar radiation	W/m²
Indoor Conditions	Indoor temperature	°C

<u>Co-Heating Method</u>: The Co-Heating test has existed for more than three decades for many purposes. The performance parameters of the construction of interest, in the form of the global coefficient of heat loss (HLC) and the global solar opening coefficient, are determined by applying a linear regression analysis, assuming a simplified thermal equilibrium and an aggregate performance data. Therefore, we observe the aggregate performance of its components. A common method to evaluate this is the Co-Heating test. This test essentially represents an almost stationary test based on the linear regression analysis of the aggregate building performance data acquired during the appropriate heating experiments. During a co-heating test, the investigated dwelling is heated homogeneously at an indoor temperature in a steady state of 25 ° C, using electric heaters and fans scattered throughout the building. The use of electrical energy, indoor and outdoor air temperatures and relative humidity, wind speed and direction and, finally, solar radiation are controlled throughout the test. The influence of the transient effects induced by the loading and unloading of the thermal mass of the building can be reduced by carefully selecting the period of the experiment and averaging the collected data over a sufficient period.

Using the regression analysis, the indoor and outdoor supervised conditions are related to the electric heating energy necessary to maintain constant the indoor air temperature. The coefficients describing this relationship represent thermal performance characteristics of interest: the Heat Loss Coefficient (HLC), in W / K. The total HLC constitutes a combined loss due to heat transmission and infiltration/ventilation. To decouple both, a Co-Heating test is usually combined with a blower door test or tracer gas test [20, 24, 25, 65, 66].

According to specifications of the standard ISO 13790 [22], you can obtain measurements of heat loss or transfer coefficient (HTC) of a dwelling through co-heating tests, capturing heat loss throughout the building envelope and because of multiple heat transfer mechanisms and interacting components. The heat loss of the building achieved by Co-Heating tests has some alternatives and advantages over discrete measurements of the unique mechanisms of heat loss (e.g., infiltration measurements [67] or point measurements (e.g. measurements of U-values in situ [68]).

D. Butler (2013) [24] uses the regression methodology to estimate the HLC (equation (2), the solar aperture (S_a) of the whole building referred to the south vertical global solar radiation. Being the period carried out for Co-Heating test in winter to reduce the effect of solar radiation on the measured electrical heat input.

$$(Q + K) = HLC(\Delta T) - S_a V_{sol} \qquad (2)$$

Where:

Q [kW]: all heating and ventilating systems energy inputs inside the building

K [kW]: all the other heat gains inside the building (solar gains and Q not included).

ΔT[C]: Difference between Ti[C], the indoor air temperature and To[C], the outdoor air temperature.

S_a [m²]: solar aperture of the whole building referred to the south vertical global solar radiation.

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V_{sol} [kW/m²]: Vertical south solar radiation.

To solve this estimation, the physical variables are obtained from five different types of sensors showed in Table 5.

Table 5. Physical variables measured in Co-Heating test.

Typology	Sensor measure	International System Unit
Energy Consumption	Total electricity whiting the buildings envelope	Wh, KWh, MWh
	Total energy consumption (Heating)	Wh, KWh, MWh
Weather	Outdoor temperature	°C
	Vertical global south solar radiation.	W/m²
Indoor Conditions	Indoor temperature	°C

2.5.2. Sensor accuracy of monitoring systems used in experimental test for evaluating the building envelope HLC: A reasearch project sample.

In order to have a reference and know the current accuracy used in experimental test to estimate the HLC, this section present the sensors used in an occupied big office building (Table 6) together with the communication protocol, hardware and software (Table 7) implemented. The MCSs was implemented in a public building of the University of the Basque Country under the 7th Framework Program for Research (FP7) [69] project A2PBEER [10] and where an energy characterization [19] was carried out. This building has been retrofired and is being energetically monitored in current. Besides, their MCS has not implemented any FDD method.

Table 6. Monitoring System of public building of the University of the Basque Country.

Typology	Measurement	Device identification	Accuracy
Energy consumption	Heating system	7 Calorimeter: **Kamstrup Multical 602 for heating**	E_T ± (0.4 + 4/ΔT)%
		(F0 1 calorimeter; F1, F2 and F3 2 calorimeters per floor)	(for the set of sensors)
	Lighting system	4 Electricity Power Meter: **1 ABB EM/S 3.16.1 meter**	± 2% for all
		3 ABB A43 meters (1 meter per floor)	
Indoor Conditions	Brightness Level (lux)	13 Brightness sensors: **Siemens 5WG1 255-4AB12**	-
	Air Quality (ppm CO_2)	13 Air quality, Temperature and Humidity Sensors: **ARCUS SK04-S8-CO2-TF**	± 1% Measurement Error
	Temperature (ºC)		± 0.5°C
	Relative Humidity (%)		± 3% RH
Weather	Brightness Level (lux)	1 Weather Station on roof: **ELSNER 3595 Sun tracer KNX basic**	± 35% at 0...150,000 lux
	Temperature (ºC)		± 0.5°C
	Wind Speed (m/s)		±25% at 0...15 m/s
	Rain (yes/no)		-
	Temperature (ºC)	1 Outdoors Temperature and Humidity Sensor on roof:	± 0.5°C
	Relative Humidity (%)	**ARCUS SK01-TFK-AFF**	± 3% RH
	Global Horizontal Solar Radiation (W/m²)	1 Pyranometer on roof: **ARCUS SK08-GLBS**	± 5%

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Table 7. Controlling System of public building of the University of the Basque Country.

Typology	Technology	Device Specifications	Descriptions
Communications	KNX Protocol	Bus KNX	The installation is based on devices communication via a communication bus KNX that will allow communication between all the devices present in the installation.
	Cable	Twisted pair (TP1) of the type Y (St) Y 2x2 x0, 8 mm²	Red (+) and black (-) for the bus line, and the two remaining wires are yellow and white which will be used for additional applications, additional power supply of certain components or use as an additional bus line or reserve for breakdowns.
Hardware	KNX/IP Interface	Weinzierl 730	4 lines of the Measuring System and of the lines set out, is done through IP connections. For this, each line has a KNX / IP Interface located on the KNX board of each floor.
	Web Server	For the control and monitoring of the installation is the Combridge Studio Evolution Server (CBSE) of IPAS	This device must be connected to a LAN network of each building provided with Internet access. It communicates with KNX network using KNX / IP gateways.
	Switch and router	Used by university	The university has several routers and switch that has been used.
Software	Specific KNX software tool	ETS (Unique Standard Application for Programming KNX Systems) Software.	ETS programming occurs in two different phases, the first one is creation of the topological structure of the installation, parameterization of the devices and assigning physical addresses and groups, and a second phase consists of the physical programming of the installation directly in the building.

This project is a sample of how the automation of buildings is being implemented in research works. This example and the literature studied next section demonstrate the need to implement MCS in experimental tests to have the energy characterization of the building envelope and a correct estimate of HCL.

2.5.3. Different sensors sets used in research projects to estimate the HLC and buildings-energy envelope performance: The monitoring system and Smart Building Controller

In order to know the MCSs used to measure physical variables, which are necessary to estimate the HLC and BEP; different literatures has been selected with the purpose of identify sensors, controls, hardware and software employed in research studies. In addition, the technology used will be analyze in discussion section to know the possibility of implementing in BAS and domotic systems the MCS used to estimate HLC and BEP with the current technology.

The choice of literature has taken into account several requirements in order to ensure the literature was based not only on an analytical study of HLC and BEP estimation, but also in studies with an experimental basis. The experimental basis should be made in buildings, housing or prototypes monitored, so that within the selection studies based on simulations or purely theoretical and analytical analysis have not been taken into account, so the requirements taken into account are:

1) Studies based on experimental tests of buildings, houses or prototypes of small scale.
2) Studies that have been developed with the objective of estimating the HLC and BEP in experimental buildings, houses or prototypes of these on a small scale, and that also use one or more of following methods:
    a) Co-Heating method.
    b) Energy balance.

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c) Average Method.
d) Corrected Average Method.
e) Other methods (e.g. statistical methods) but that also include at least one of the following studies:
    - Energy Consumption.
    - Energy Balance.
    - Infiltration.
    - Local U-Value.
    - Other Energy Analysis (e.g. estimate heat dynamic of buildings).

Table 8 shows the relation of references selected for this study with the corresponding methods and studies carried outs since 1978 to 2018, which are reports, journal articles and conferences publications. The literature studied includes reports of first studies about Co-Heating Method in 70's decade [70] developed by the U.S. Energy Department [71] , which analyze the sensors, controls, instrumentation, hardware and software necessary for MCS to HLC estimation and building envelope performance. Moreover, in second decade of 21th century, an increase of experimental tests is observed, having a greater concentration of publications in 2015, 2016 and 2017.

The Table 9 shows the sensors, controls, hardware, software and devices used in experimental tests of each selected literature together with the verification of FDD method used, wich was not implemented in any of the experimental tests studied. The next section the results and study of MCS is developed with a qualitative and quantitative analysis. As well, the methodology and criterial used to obtain the result are described.

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Table 8. List of publications used in the analysis of the MCS employed to estimate the HLC and the energy envelope performances of in-situ buildings, and the methods used in estimations.

			HLC and Energy Envelope Performant Methods and Other Estimation used										
Reference	**Publication Year**	**Type of publication**	Co-Heating Method	Regression Method	Average Method	Corrected Average Method	Energy Consumption estimation	Energy Balance estimation	Infiltration estimation	U-Value estimation	R-Value estimation	Other Studies of Energy Analysis to estimated	Other studies and methodologies
[70]	1978	Report	X				X		X				
[72]	1979	Paper	X										
[73]	1979	Report	X									X	
[74]	1980	Report	X						X				
[75]	1985	Report		X				X	X			X	X
[76]	1985	Report		X				X				X	X
[77]	1995	Paper										X	X
[78]	2000	Paper	X				X						
[79]	2001	Paper					X						X
[80]	2005	Paper	X										
[81]	2007	Paper	X										
[82]	2013	Paper	X						X	X			
[83]	2015	Conference Paper	X										
[84]	2015	Conference Paper										X	X
[85]	2015	Conference Paper	X						X				
[86]	2015	Paper					X	X				X	X
[87]	2016	Paper	X						X	X			
[19]	2016	Paper	X			X							
[88]	2016	Paper	X							X			
[89]	2017	Paper	X										
[90]	2017	Paper	X							X	X		
[91]	2017	Paper		X	X							X	X
[92]	2018	Paper	X										
[93]	2018	Paper	X										

177 **Table 9.** Monitoring System in review literature since 1979 to 2018 specified by autors to determinate the HLC and energy envelope performance.

Reference	Publication Year	Type of publication	FDD	Sensors																							Actuators		Control System						Other Devices		
			Specify the application of FDD method to MCS	Indoor Air Temperature	Surface Temperature (out and indoor)	CO_2	Interior Relative Humidity	Heat Fluxes	Infiltration	Infrared Thermography	Electricity Meter	Gas Meter	Heat Meter	HVAC Air Flow	Light Power Meter	Illumination Level	Outdoor Air Temperature	Exterior Relative Humidity	Global Vertical Solar Radiation Intensity	Global Horizontal Solar Radiation Intensity	Diffuse Solar Radiation Intensity	Brightness Level	Wind Speed Anemometer	Wind Direction	Atmospheric Pressure	Precipitation	Thermostat	Other Building Devices to Control	Protocol Communication	Getaway or Transmitters	Data logger	Data Processor	SCADA	Computer	Heating	Fans	Electric Radiator
[70]	1978	Report	No	X					X	X	X	X	X		X		X	X	X	X	X		X	X		X	X	X	X		X	X		X			
[72]	1979	Paper	No	X					X		X						X										X								X		
[73]	1979	Report	No	X							X						X		X	X								X			X			X			
[74]	1980	Report	No	X					X		X																X				X	X			X		X
[75]	1985	Report	No	X	X	X		X	X		X	X	X					X	X	X	X		X	X			X	X			X	X		X			
[76]	1985	Report	No	X							X	X	X				X		X	X			X	X							X			X			
[77]	1995	Paper	No	X					X								X		X									X									X
[78]	2000	Paper	No	X							X																				X	X					
[79]	2001	Paper	No	X					X		X						X		X										X			X					
[80]	2005	Paper	No	X			X				X						X	X		X							X								X		
[81]	2007	Paper	No	X						X	X						X	X	X								X		X	X	X			X		X	X
[82]	2013	Paper	No	X				X	X	X	X						X																			X	X
[83]	2015	Conference Paper	No	X							X						X		X										X		X	X		X		X	X
[84]	2015	Conference Paper	No	X													X	X	X	X	X		X	X				X			X			X	X		
[85]	2015	Conference Paper	No	X					X								X		X	X	X		X	X													
[86]	2015	Paper	No	X		X	X				X			X		X	X		X	X	X										X	X					
[87]	2016	Paper	No	X	X		X	X	X		X						X		X	X	X																X
[19]	2016	Paper	No	X		X	X						X		X	X	X	X		X		X	X				X										
[88]	2016	Paper	No	X				X			X		X				X	X	X				X	X			X	X			X				X	X	
[89]	2017	Paper	No	X				X	X		X			X			X												X		X	X				X	X
[90]	2017	Paper	No	X				X	X	X	X						X							X			X				X					X	X
[91]	2017	Paper	No	X	X			X			X		X				X	X	X	X	X		X	X													
[92]	2018	Paper	No	X				X			X	X					X										X									X	X
[93]	2018	Paper	No	X					X	X	X								X	X	X						X									X	X

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3. Results and discussion

This section will present the qualitative and quantitative analysis of equipment, technical specification level of the MCS' described, and presented in twinty four bibliographies reviewed, of which the 71% used the Co-Heating Method and a 13% used other regression methods. On the other hand one publication estimate the HLC with Corrected Average Method and another one with Average Method, where each one represents 4% of total publications. To estimate local U-Values, two of four publication used ISO9869:1994, one publication does not specify the methology implemented and another was based in ISO 6946:2007 [85]. The 29%, seven publication, have implemented other methodologies to estimate HLC and BEP, like for example estatistical methods among others. These values are especified in Table 1, Table 14 and Table 15.

The objective of qualitative and quantitative analysis is to identify the MCSs currently used to estimate HLC and BEP in order to:

- Identify the technology used in experimental tests.
- Analyze the integration of MCSs in BAS.
- Identify the currently state of FDD methods implemented in MCSs.

Based on data recompilation of Table 9, a qualitative and quantitative analysis has been made in function of equipment and technical specification level of the MCS' described and presented in literature's methodology reviewed.

To analyze the MCS technologies used in experimental tests of the selected review bibliography; different levels have been defined according of technical specifications that selected publications describe in their experimental methodology. For this, the MCS equipment implemented to collect and process the physical variables to develop the methods for the HLC and BEP estimation, which these publications propose, is characterized. Three levels are defined, Level A, B and C. These levels are quantified with 1, 0.5 and 0 respectively and the detail degree that define the level is showing in Table 10.

Table 10. Description of level quantification used to analyze the monitoring and controlling system of reviewed literature.

Levels	Detail degree of technical specifications	Quantitative Value
Level A	High degree specification	1
Level B	Partial specification	0.5
Level C	There is not specification	0

The evaluated criterial has been divided into two groups, one to analyze the monitoring system that include the sensors and other one to analyze the controlling system that include controls, communication protocols, software and hardware. The
Table **11** shows the criterial considered to analyze the MCSs' specification degree of technologies used in research projects of literature reviewed. The MCSs' specification degree help to identify the importance degree of MCSs in HLC and BEP estimation and let know the reason why there is a difficulty in identifying MCSs technologies used in experimental tests.

Table 11. Criterial to evaluate with specification levels.

ANALIZED CRITERIALS	
Devices of Monitoring System	**Devices of Controlling System and Data Acquisition System**
Specify the Model or Type	Specify the Model or Type of control devices
Specify the Data Sheet	Specify the Data Sheet
Details the Accuracy	Specify the Protocol Communications
Specify the criterion used for determinate the Type of Monitoring System	Specify the operating characteristics of Hardware and Software
	Specify the Hardware and Software type
	Specify the criterion used for determinate the type of Controlling System used

Table 12 shows the review bibliography with the analyzed criterial and their corresponding level in each of them. Analyzing the Monitoring System's Devices criterial is observed the 50% of literatures studied are in level C and it has not been possible to identify the type or model of sensors used in those experimental test, the 83% has not specify the data sheet and a 58.3% did not specify the sensor's accuracy either. Besides the 79.2% did not describe the decision criterial to select the sensors (economic, technical or other criterial).

Regarding the Controlling System's Devices, they show a similar tendency as Monitoring System's Devices, just around of 12.5% make a complete description specifying the model or type of control devices, the data sheet and explain the criterial used to determinate the control system in function of its technical requirements. On the other hand, the 20.8% specify protocol communication, software and hardware. In addition, just a 25% specify the operating characteristics of hardware and software used to controlling and processing the collected data.

Studying the publication, it has been possible determinate the sensors and devices used when these were not included explicitly in the methodologies because they were used in calculus analysis, tables and/or data graphics. In this way, it was possible to know in some case the use of sensors in the experiment test. Even so, there are publications that did not specify the devices used and just give the results, not being possible to identify the devices used in the experimental test. The Table 14 and Table 15 show the sensor, devices, software and hardware identified in selected literature. Has been possible identify the 100% of literatures define the use of sensors to measure the interior temperature, an 83% to measure the exterior temperature and around 13% measure surface temperature. The difference between the exterior and interior temperature maybe is because this data was collected using weather station but neither was found if this measure is collected by this station. Just the 13% has used CO_2 sensors and relative humidity sensors in the tests.

Besides, there was found that the 21% of experimental tests used infrared thermographic and a 50% use different devices to estimate the infiltration, only the 33% used local heat flow sensors. Around of 30% to 50% use collected data from weather station, where the 50% specify measure the horizontal global radiation, a 63% the vertical global radiation, 33% the diffuse radiation. The 33% has used relative humidity sensors.

The 83% use an electricity meter to measure the energy consumption. Likewise, there was found the use of other meter sensor, the 17% used gas meters, 25% used heat meters and an 8% used HVAC air flow and specific sensor to measure the light power consumption an 8%.

The 71% has used the Co-Heating method for its experimental tests, where the 88% specify the use of electricity meter and an 82% the use of sensor to measure the exterior temperature; a 29% measure exterior RH and only a 18% interior RH. Around 40% measure solar radiation and 14%

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measure wind direction and wind speed. Just a 53% and 47% describe the use of electrical radiator and fans respectively. The 53% measure air infiltration, 29% use infrared thermographic, 35% use heat flow and only a 6% measure surface temperature. A 24% use a heating and HVAC systems at the same time in the experimental; the use of these buildings systems in some case is to maintain an external condition when there is a building prototype or to avoid the stratification during different tests. The physical variables showed in Table 5 are measured in Co-Heating methods developed in selected publications.

Experimental tests that use other regression methods have measured in a 100% the electricity consumption, heating, horizontal and vertical solar radiation, wind speed and direction speed. No experiment has used any fan or electrical heating. Around the 67% have measured surface temperature, heat flow, gas consumption, diffuse solar radiation, outdoor temperature and exterior RH. Finally only a 33% measured CO_2 concentration.

The Average Method used in experimental test devices to measure interior, exterior and surface temperature, heat flow, electricity consumption, exterior relative humidity, horizontal and vertical solar radiation, wind direction, exterior pressure and has used heating meters. Besides, Corrected Average Method measured interior and exterior temperature, CO_2 concentration, indoor RH and light power consumption, illumination levels, exterior relative humidity, horizontal solar radiation, exterior pressure and has used heating meters. These both method, only were used by the one of the experimental tests.

A 17% of experiment test have used methods different to Co-heating, regressions, Average Method and Corrected Average Method. The four publication used devices to measure interior and exterior temperature, CO_2 concentration, indoor and outdoor RH, air infiltration, electricity, gas and light power consumption, illumination levels, vertical, horizontal solar radiation, precipitations, wind speed, wind direction and has used heating meters.

All methods have used actuators to control different physical variables in experiment tests. The 46% used thermostats and a 25% has used other devices controls for example to open or close windows among others. The 59% and 33% of publications that analyzed the Co-Heating test and other regression method, have use thermostats respectively.

No project mentions the use of a SCADA for collect and process the data, the 54% used to process data a Data Logger and a software to process the information using a computer. The 67% of publication that have implemented a regression methods specify the use of Data Logger, other 33% use an specific data processor and a 67% computers and software to do the analysis data. In case of experiments that analyze the Co-Heating method a 53% used a Data Logger and a 24% a software to process data with a computer.

The communication protocol used were not identify, just around 21% of publication specify some characteristic of the data transmission, and only one publication specify the use of a getaway or transmitter.

The results shows that none publication has implemented a FDD method to detect, identify and correct the error in MCSs used during the experiment tests.

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Table 12. Qualitative analysis of specification level's degree of the criterial analyzed for devices, hardware and software of MSC used in buildings or prototypes in each publication studied.

Reference	Publication Year	Type of publication	Monitoring System's Devices				Controlling System's Devices					
			Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
[70]	1978	Report	Level C	Level C	Level C	Level C	Level C	Level B	Level A	Level A	Level B	Level C
[72]	1979	Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C
[73]	1979	Report	Level A	Level A	Level A	Level A	Level A	Level A	Level A	Level A	Level A	Level A
[74]	1980	Report	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level A	Level C	Level C
[75]	1985	Report	Level B	Level B	Level B	Level B	Level B	Level B	Level C	Level A	Level A	Level A
[76]	1985	Report	Level B	Level B	Level B	Level B	Level C	Level C	Level C	Level A	Level A	Level A
[77]	1995	Paper	Level C	Level C	Level C	Level C	Level C	Level B	Level C	Level C	Level C	Level B
[78]	2000	Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level B	Level C
[79]	2001	Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level B	Level B	Level B	Level C
[80]	2005	Paper	Level B	Level C	Level C	Level C	Level A	Level A	Level C	Level C	Level C	Level B
[81]	2007	Paper	Level A	Level C	Level C	Level C	Level A	Level A	Level A	Level A	Level A	Level C
[82]	2013	Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C
[83]	2015	Conference Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level A	Level B	Level B	Level B
[84]	2015	Conference Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level B	Level B
[85]	2015	Conference Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C
[86]	2015	Paper	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level A	Level C
[87]	2016	Paper	Level B	Level C	Level B	Level C	Level C	Level C	Level C	Level C	Level C	Level C
[19]	2016	Paper	Level A	Level C	Level A	Level B	Level C	Level C	Level C	Level C	Level C	Level C
[88]	2016	Paper	Level A	Level C	Level A	Level C	Level C	Level B	Level C	Level B	Level B	Level C
[89]	2017	Paper	Level A	Level C	Level B	Level C	Level C	Level C	Level A	Level B	Level B	Level C
[90]	2017	Paper	Level A	Level C	Level A	Level B	Level C	Level B	Level C	Level B	Level B	Level C
[91]	2017	Paper	Level A	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C	Level C
[92]	2018	Paper	Level C	Level B	Level B	Level C	Level C	Level B	Level C	Level C	Level C	Level C
[93]	2018	Paper	Level A	Level C	Level B	Level C	Level C	Level B	Level C	Level C	Level C	Level C

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Table 13. Quantitative analysis of specification level's degree of the criterial analyzed of MSC used in buildings or prototypes in each publication (1).

All Methods Applied

All Methods	Monitoring System's Devices				Controlling System's Devices					
24 references	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	8	1	4	1	3	3	5	6	5	3
	33.3%	4.2%	16.7%	4.2%	12.5%	12.5%	20.8%	25%	20.8%	12.5%
Level B	4	3	6	4	1	7	1	5	8	4
	16.7%	12.5%	25%	16.7%	4.2%	29.2%	4.2%	20.8%	33.3%	16.7%
Level C	12	20	14	19	20	14	18	13	11	17
	50%	83.3%	58.3%	79.2%	83.3%	58.3%	75.0%	54.2%	45.8%	70.8%

Co-Heating Method

Co-Heating Method	Monitoring System's Devices				Controlling System's Devices					
17 references 71%	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	7	1	4	1	3	3	5	4	2	1
	41.2%	5.9%	23.5%	5.9%	17.6%	17.6%	29.4%	23.5%	11.8%	5.9%
Level B	2	1	4	2	0	5	0	4	6	2
	11.8%	5.9%	23.5%	11.8%	0%	29.4%	0%	23.5%	35.3%	11.8%
Level C	8	15	9	14	14	9	12	9	9	14
	47.1%	88.2%	52.9%	82.4%	82.4%	52.9%	70.6%	52.9%	52.9%	82.4%

Regression Method

Regression Methods	Monitoring System's Devices				Controlling System's Devices					
3 references 13%	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	1	0	0	0	1	0	0	0	2	2
	33,3%	0,0%	0,0%	0,0%	33,3%	0,0%	0,0%	0,0%	66,7%	66,7%
Level B	2	2	2	2	0	1	1	0	0	0
	66,7%	66,7%	66,7%	66,7%	0,0%	33,3%	33,3%	0,0%	0,0%	0,0%
Level C	0	1	1	1	0	2	2	3	1	1
	0,0%	33,3%	33,3%	33,3%	0,0%	66,7%	66,7%	100,0%	33,3%	33,3%

Average Method

Average Method	Monitoring System's Devices				Controlling System's Devices					
1 reference 4%	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	1	0	0	0	0	0	0	0	0	0
	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Level B	0	0	0	0	0	0	0	0	0	0
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Level C	0	1	1	1	1	1	1	1	1	1
	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%

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Table 13. Quantitative analysis of specification level's degree of the criterial analyzed of MSC used in buildings or prototypes in each publication (2).

Corrected Average Method

Corrected Average Method	Monitoring System's Devices				Controlling System's Devices					
1 reference 4%	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	1 100%	0 0%	1 100%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
Level B	0 0%	0 0%	0 0%	1 100%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
Level C	0 0%	1 100%	0 0%	0 0%	1 100%	1 100%	1 100%	1 100%	1 100%	1 100%

Other methods applied

Other methods applied[17]	Monitoring System's Devices				Controlling System's Devices					
7 references 29%	Specify the Model or Type	Specify the Data Sheet	Details the Accuracy	Specify the criterion used for determinate the Type of Monitoring System	Specify the Model or Type of control devices	Specify the Data Sheet	Specify the Protocol Communications	Specify the operating characteristics of Hardware and Software	Specify the Hardware and Software type	Specify the criterion used for determinate the type of Controlling System used
Level A	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 25%	1 25%	1 25%
Level B	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 25%	1 25%	1 25%	3 75%
Level C	4 100%	4 100%	4 100%	4 100%	4 100%	4 100%	3 75%	2 50%	2 50%	0 0%

[17] Other methods studied in different to Co-Heating, Regression, Average Method and Corrected Average Method.

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Table 14. Quantitative analysis of references studied by methodologies: Global analysis of method used, MCS's fault detection and sensor type used for measure physical variables in each methodology analyzed.

		Global Analysis	FDD	Sensors																						
			Specify the application of fault detection method	Indoor Air Temperature	Surface Temperature	CO_2	Interior Relative Humidity	Heat Flow	Infiltration	Infrared Thermography	Indoor Brightness Level	Electricity Meter	Gas Meter	Heat Meter	HVAC Air Flow	Light Power Meter	Outdoor Air Temperature	Exterior Relative Humidity	Global Vertical Solar Radiation	Global Horizontal Solar Radiation	Diffuse Solar Radiation	Outdoor Brightness Level	Wind Speed	Wind Direction	Atmospheric Pressure	Precipitation
ALL LITERATURES STUDIED	Total references	**24**	0	24	3	3	4	8	12	5	2	20	4	6	2	2	20	8	15	12	8	1	8	8	0	1
	Percentage rate	**100%**	0%	100%	13%	13%	17%	33%	50%	21%	8%	83%	17%	25%	8%	8%	83%	33%	63%	50%	33%	4%	33%	33%	0%	4%
CO-HEATING METHOD	Total references	**17**	0	17	1	1	3	6	9	5	1	15	2	3	1	2	14	5	8	7	4	1	4	4	0	1
	Percentage rate	**71%**	0%	100%	6%	6%	18%	35%	53%	29%	6%	88%	12%	18%	6%	12%	82%	29%	47%	41%	24%	6%	24%	24%	0%	6%
REGRESSION METHOD	Total references	**3**	0	3	2	1	0	2	1	0	0	3	2	3	0	0	2	2	3	3	2	0	3	3	0	0
	Percentage rate	**13%**	0%	100%	67%	33%	0%	67%	33%	0%	0%	100%	67%	100%	0%	0%	67%	67%	100%	100%	67%	0%	100%	100%	0%	0%
AVERAGE METHOD	Total references	**1**	0	1	1	0	0	1	0	0	0	1	0	1	0	0	1	1	1	1	1	0	1	1	0	0
	Percentage rate	**4%**	0%	100%	100%	0%	0%	100%	0%	0%	0%	100%	0%	100%	0%	0%	100%	100%	100%	100%	100%	0%	100%	100%	0%	0%
CORRECTED AVERAGE METHOD	Total references	**1**	0	1	0	1	1	0	0	0	1	0	0	1	0	1	1	1	0	1	0	1	1	0	0	0
	Percentage rate	**4%**	0%	100%	0%	100%	100%	0%	0%	0%	100%	0%	0%	100%	0%	100%	100%	100%	0%	100%	0%	100%	100%	0%	0%	0%
OTHER METHODS APPLIED	Total references	**4**	0	4	0	1	1	0	2	1	1	4	1	1	1	1	3	1	3	2	2	0	1	1	0	1
	Percentage rate	**17%**	0%	100%	0%	25%	25%	0%	50%	25%	25%	100%	25%	25%	25%	25%	75%	25%	75%	50%	50%	0%	25%	25%	0%	25%

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Table 15. Quantitative analysis of references studied by methodologies: Global analysis of method used, actuators, controls systems and devices used in each methodology analyzed.

			Actuators		Control System						Other Devices			
		Global Analysis	Thermostat	Other Building Devices to Control	Protocol Communication	Getaway or Transmitters	Data logger	Data Processor	SCADA	Computer	Heating	HVAC	Fans	Electric Radiator
ALL LITERATURES STUDIED	Total references	**24**	11	6	5	1	13	8	0	7	5	5	8	10
	Percentage rate	**100%**	46%	25%	21%	4%	54%	33%	0%	29%	21%	21%	33%	42%
CO-HEATING METHOD	Total references	**17**	10	3	4	1	9	5	0	4	4	3	8	9
	Percentage rate	**71%**	59%	18%	24%	6%	53%	29%	0%	24%	24%	18%	47%	53%
REGRESSION METHOD	Total references	3	1	1	0	0	2	1	0	2	0	0	0	0
	Percentage rate	13%	33%	33%	0%	0%	67%	33%	0%	67%	0%	0%	0%	0%
AVERAGE METHOD	Total references	**1**	0	0	0	0	0	0	0	0	0	0	0	0
	Percentage rate	**4%**	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CORRECTED AVERAGE METHOD	Total references	1	1	0	0	0	0	0	0	0	0	0	0	0
	Percentage rate	4%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
OTHER METHODS APPLIED	Total references	**7**	1	1	2	0	3	4	0	1	0	1	0	0
	Percentage rate	**29%**	25%	25%	50%	0%	75%	100%	0%	25%	0%	25%	0%	0%

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4. Conclusions

There are evidences the energy efficiency research is focused on the use of automated projects to collect physical data, transfer the information using standard communication protocols, and through of software use, process all information to control and monitor physical variables and make the data treatment. Researchers could use a centralized automation in their projects to facilitate the collection of a large amount of data. This could help them not only to understand the building envelope behavior but also develop new services that can be integrated into the market of BAS.

Currently in BAS, there is no evidence of integration of in-use building energy monitoring system to characterize the building envelope. Which has as objective to know how efficient the envelope is after the construction or retrofit in order to determinate the discrepancy between the buildings design and building in use, and to identify future retrofits of building envelope.

The equipment necessary to carry out the estimation of the HLC and BEP is made up of sensors, controllers, software, hardware, communication protocols and other devices and components of MCSs. At the end of the 70's and the beginning of the 80's, there are studies about different monitoring technologies and cost / precision criteria for equipment selection used in the energy monitoring of buildings to estimate the HLC. Currently there is no evidence of recent studies that make comparisons between the different sensors and equipment used in energy monitoring with existing technologies. Neither there is no evidence of monitoring systems to estimate the HLC and BEP in BAS or domotic systems.

The publications on HLC and BEP do not specify the selection criteria of the monitoring systems used in research projects, which shows that there is no standardization in the type of MCS that should be used to perform experimental tests in these estimations. It is also evident experiment tests focus more on developing the HLC and BEP estimation methods than the analysis to determinate the criterial to choice the MCSs. This trend is given although the sensors used to measure physical variables are a critical and important part in the reliability of data collected to perform the HLC and BEP estimation. It has been observed too the MCSs used to estimate HLC allows analyze and estimate others parameters used to determinate the BEP. Besides the physical variables necessary for these estimations are collected in current BAS and domotic systems in order to determinate the user comfort, electricity consumption and for the control of their buildings systems. This makes possible that the experimental tests used to estimate the HLC and BEP can be designed under the perspective of BAS and domotic systems in order to introduce the HLC and BEP estimations in these automation systems. For this, the experimental tests should develop selection criteria of the MCSs in the research projects in order to standardize them.

The standardization of the MCSs used in the HLC and BEP estimation in experiment tests needs further research in order to ensure the physical data are accurate enough to rigorously apply the HLC estimation methods. In this way, the HLC estimate for the emission of reliable EPCs according to the requirements of the legislation may be used, being able to be integrated these estimates in BAS and domotic systems. It is also necessary to emphasize the importance of defining the criteria in MCSs election in order to granter technologies accurate, reliable, profitable and safe against cyber-attacks.

No publication has been found that develops AFDD methods to whole monitoring system of a building in BAS or domotic systems. Neither has been found studies that estimate the HLC and BEP testing different sensor technologies to know what discrepancies there is in HLC estimation, and what is the sensor response in buildings-energy monitoring systems. The methods analyzed to estimate the HLC and BEP are based in errors and fabric accuracy of devices. As an example, to understand the measure discrepancies of temperature, RH, CO2 levels, energy consumption, solar radiation and other physical variables, it is necessary to know the sensor characteristics used in buildings automation and research projects that estimate the HLC and BEP. For this is essential knowing in real-time the faults during the experimental tests to analyze the impact in calculus, and determinate the error discrepancies with manufacturing data sheet, being necessary the implementation of AFDD method in MCSs of experimental tests.

The literature studied in this paper gone the evidence that AFDD methods are developed on building systems like fan coils, HVAC, heat pump, air conditioners, commercial refrigerators, lightings, water heater, chillers and cooling towers, AHUs and VAV boxes. A specific method for all MCSs used in BAS and domotic systems, has not been found, being essential integrate FDD methods for all parties that make up these MCSs. It is necessary to develop FDD method to calibrate, predict and detect the MCSs' error of all its devices. This would facilitate the maintenance allowing self-regulation and calibration of the system to increase the accuracy and reliability of the studies.

The research lines need to focus on the effect of HLC and BEP estimation using different sensor technologies with laboratory accuracy and market sensor accuracy. This study could allow the development a monitoring kit and controlling specification to estimate HLC and BEP, together their layout in buildings. In addition, it is necessary knowing how is the discrepancy of HLC and BEP estimation using the technology of current BAS and domotic system, in order to know if with the market technology is possible determinate the building envelope efficiency after the construction of existing buildings with current technology. So know how to integrate a MCSs standardized to estimate the HLC and BEP in BAS and domotic systems for new and existing buildings.

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Appendix A

Table 16 Acronyms list.

Acronym	Meaning
A2PBEER	Affordable and Adaptable Public Buildings through Energy Efficient Retrofitting
AFDD	Automated Fault Detection and Diagnosis
AHU	Air Handling Unit
ANN	Artificial Neural Network
ANSI	American National Standards Institute
AR	Autoregressive
ARM	Autoregressive Moving Average
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
BACnet	Data Communication Protocol for Building Automation and Control Networks
BAS	Building Automation Systems
BCS	Building Control System
BEP	Buildings Envelope Performances
BMS	Building Management System
CO_2	Carbon Dioxide
CORDIS	Community Research and Development Information Service of European Commission
CSIC	Superior Council of Scientific Investigations of Spain
DHW	Domestic Hot Water
EEB	Energy Efficiency of Buildings
EED	Energy Efficiency Directive
EHS	European Home System
EIB	European Installation Bus
EPB	Energy Efficiency of Buildings
EPBD	Energy Performance of Buildings Directive
EPCs	Energy Performance Certificates
ETS	Unique Standard Application for Programming KNX Systems
EU	Europe Union
FDD	Fault Detection and Diagnosis
FP7	7th Framework Programme for Research and Technological Development
HLC	Heat Loss Coefficient
HTC	Heat Transfer Coefficient
HVAC	Heating, Ventilation and Air Conditioning systems
ICT	Information and Communication Technologies
IEA	International Energy Agency
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
KPI	Key Performance Indicators
LONWork	Local Operating Network

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Acronym	Meaning
MCS	Monitoring and Controlling System
Mtoe	Million Tons of Oil Equivalent
OSGI	Open Services Gateway Initiative
PCA	Principal Component Analysis
PLC	Programmable Logic Controllers
RD&D	Research, Development and Design
RF	Radio Frequency
RH	Relative Humidity
RTU	Remote Terminal Unit
SAP	Standard Assessment Procedure
SCADA	Supervisory Control And Data Acquisition
SVM	Support Vector Machine
TCP/IP	Transmission Control Protocol / Internet Protocol
UK	United Kingdom
UPnP	Universal Plug and Play
VAV	Variable Air Volume
WPAN	Wireless Personal Area Networks

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