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A SWOT FRAMEWORK TO INVESTIGATE THE INTEGRATION BETWEEN BUILDING MANAGEMENT SYSTEMS AND FAULT DETECTION AND DIAGNOSIS TOOLS

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ABSTRACT

This paper presents a research work carried out under the umbrella of the CASCADE project, which is a European FP7 research project which is developing facility-specific measurement-based energy action plans for the airport energy managers that are underpinned by Fault Detection Diagnosis (FDD). The paper first describes the context of the project then it focuses on Building Management Systems describing the current status of the technology and presenting an outlook on their future development. Then a Strengths Weakness Opportunity and Treads (SWOT) framework is defined with the aim of verifying the suitability of an installed BMS system to incorporate Fault Detection and Diagnosis (FDD) tools.

Keywords: Building Management Systems (BMS), Energy management, Fault Detection and Diagnosis (FDD), SWOT framework, Heating Ventilation and Air Conditioning(HVAC)

1. INTRODUCTION

Buildings consume 40% of the overall energy in both EU and US [1], and building performance at operation does not normally reflect design expectations.

Building Management Systems (BMS) or Building Automation Systems (BAS) are used to facilitate systems control and building energy management. From literature and funded projects (e.g. Building EQ [2]), it was concluded that many existing BAS/BMS systems are not primarily designed for the analysis of building performance and cannot support this by their own. Fault Detection and Diagnosis tools are currently proposed as a solution to the problem; however the integration is not an easy task. The restrictions are caused by technical issues e.g, data availability as well as administration issues like not standardised or proprietary protocols. This paper proposes a comprehensive Strengths Weakness Opportunity and Treads (SWOT) framework that aims at verifying the suitability of an installed BMS system to incorporate the fault detection and diagnosis tools. This work was carried out under the umbrella of the CASCADE project.

2. THE CONTEXT: CASCADE PROJECT

CASCADE is a European FP7 research project [3] (PSE.AG, 2012) which is developing facility-specific measurement-based energy action plans for the airport energy managers that are underpinned by Fault Detection Diagnosis (FDD) methods (Figure 1). A framework and methodology for building customized ICT solutions is under development in order to integrate with and on the basis of the existing ICT infrastructure and operational procedures. A measurement framework and minimal data set will be established to control and benchmark the equipment performance, to optimize user behaviour, and to match client specifications. FDD enables the state-of-the-art energy management because it can be used to suggest problems in system design, equipment efficiency, and operational settings. CASCADE is aiming also at turning FDD into the actionable information by developing an energy action plan that links Actions-Actors-ISO Standards [4] (ISO, 2011) through a web-based management portal. The developed ICT solutions will be able to integrate with existing systems and will target a 3-year return on investment and 20% reduction of energy consumption and 20% reduction of CO_2 emissions. CASCADE will achieve these objectives in time by:

1. Engaging the client, determining their needs, and encouraging organisational change
2. Integrating new ICT technologies with the systems present at client facilities
3. Collecting data on user operation and equipment performance

4. Applying fault detection methods across operational scenarios and equipment performance benchmarks
5. Making an Energy Action Plan that links actors, actions, and ISO standards based on facility specific data and providing cost/benefit (kWh, CO2, Euros).

CASCADE approach focuses to the actions which airports can take in order to address GHG sources within their control and influence, fully in the line with ACI guidelines and recommendations for the future strategic airport planning and management [5]. Energy management actions in large organizations, such as airports, span across different levels from the top level with the overall energy policy and planning to the bottom with scheduled and emergency based operation and maintenance. In order to support top level energy management it is important to better understand the starting point of an airport in relation to its energy consumption and set reasonable targets.

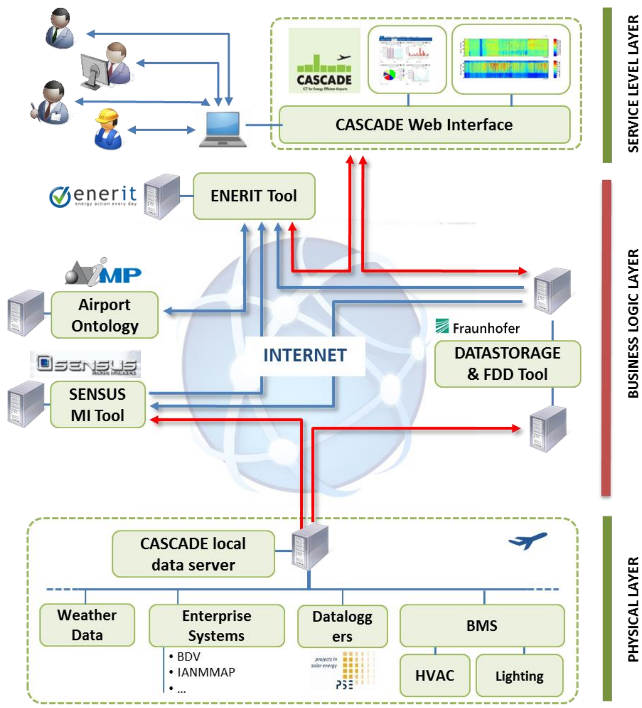

Figure 1 CASCADE solution overview

The work presented in Section 3 focuses on Building Management Systems describing the current status of this technology, its potential for incorporating Fault Detection and Diagnosis (FDD) tools and its expected future development. Section 4 defines a framework to analysed and assess existing BMS in regard of their capability to cope with Fault Detection and Diagnosis tasks. This framework is formalised in line with to the Strengths Weakness Opportunity and Treads (SWOT) approach.

3. BUILDING MANAGEMENT SYSTEMS

A Building Management System is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical systems. Though specific components may differ, these systems normally include heating, ventilation and air conditioning (HVAC), lighting, power, security, and fire protection systems. The main tasks of a BMS are:

- Controlling electrical and mechanical components;
- Monitoring environmental and technical variables in the controlled areas;
- Optimising the operation of the facilities

All of these aimed at maintaining predefined comfort/indoor conditions while maintaining levels of safety and efficiency of the system.

In accordance with the European Committee for Standardisations [6], BMS network and communications hardware within an intelligent building may be divided into three areas:

- Level 1: Field level, covering sensor and actuators, lighting systems
- Level 2: Automation level, covering the outstation/controllers
- Level 3: Management (i.e. supervisory) level

Building elements communicate among themselves and with the central control using communication protocols. Protocols are defined by the data structures that explain the format and meaning of each data (almost like a dictionary that explains a word's spelling and meaning). Both devices have to know the data structure in order to facilitate the exchange of data. The data exchange usually happens over some physical wire (such as on a twisted pair RS485 or Ethernet CAT5 cable). It can also happen wirelessly over wireless networks . Key characteristics for protocols in BMS are:

1. Being open-source or proprietary: A protocol is open-source when the creator of the protocol makes it readily available to everyone. Proprietary protocols are those that make the protocols restricted to the creator of the device by not sharing the data structure thus preventing others from using it or developing devices that can communicate through that protocol.
2. Standard: A standard protocol requires all parties from developers to end-users to agree on a data structure that can be implemented on their respective devices. If there is consistency across an industry, then the protocol becomes an industry standard like BACnet or Modbus.
3. Interoperability: A protocol is inter-operable when it has the characteristic that makes a controller from one vendor can be replaced with a controller from a different vendor.

Communication protocols often used in BMS include: BACnet, ModBus, Lontalk (LonWorks), KNX, Ethernet and Internet.

3.1 Current state of BMS

The market for BMS is in a great state of flux. It is undergoing a revolutionary change in terms of technology and the abilities gained therein. Historically, building automation consisted of individual systems with simple switches, timers and alarms. These systems were hamstrung by lack of computing power and were confined to the realm of simple tasks. The rise of new age of BMS has been ushered in with the widespread use of centralised IT software solutions and electronic devices. Today's systems have the ability to perform complex tasks with a movement towards full automation and a greater reduction in man-power requirements. With the ever decreasing availability of energy and the increase in development of buildings and infrastructure, building performance is a key area for growth. BMS systems provide the opportunity to improve and measure efficiency. Therefore, building management systems form a critical facet of improving energy efficiency in buildings. Current research suggests that the use of BMS data in a framework of energy efficient measures can contribute to overall energy savings in the region of 5-25%(Costa, 2010) [7].

Early stage building management systems worked on the premise of gathering data from local controllers (HVAC, fire protection, security, etc.) and relaying this data to a central computer for monitoring. The data was then compared with norms. Where there was a significant deviation from normal an operator was alerted. Operators were not informed as to the why or what, merely that a problem existed. This meant that fault diagnosis was often a long and tedious task. Improvements and additions to the BMS required substantial re-wiring which often proved a costly enterprise. Indeed, current research suggests that 70% of costs associated with BMS relate to wiring [8]. The introduction of wireless sensor technologies and associated protocols serves to greatly reduce the cost of BMS in this regard. Modern BMS utilises micro-processors in local controllers, a system called 'distributed intelligence'. This serves to reduce the amount of data needed to be transmitted globally, with the local processors capable, through statistical analysis, of deciding which data (outliers) is pertinent the system and sending this to the central controller. These current systems allow more global control, greater monitoring and logging of data, provide fault detection and offer advice based on past events.

The current and future importance of the building management systems in the world can be grasped from looking at the market revenues of these systems from the year 2011 to 2020 shown in Figure 2 [9].

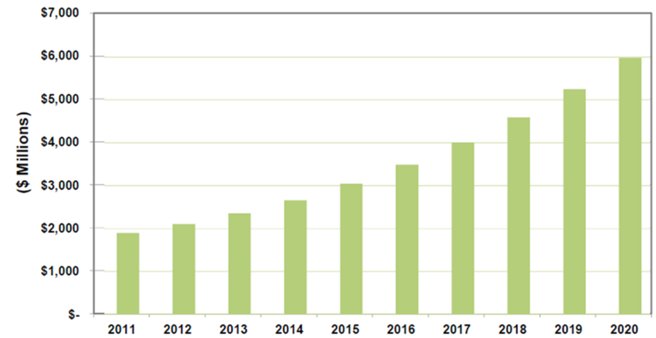

Figure 2 BEMS Market Revenue. World Markets: 2011-2020

Having a look at Figure 3 [10], the main BMS suppliers and their market shares can be seen. Most of these suppliers are already looking at the future of the BMS by using open and standard communication protocols, introducing fault detection and diagnosis capabilities among other improvements on their systems.

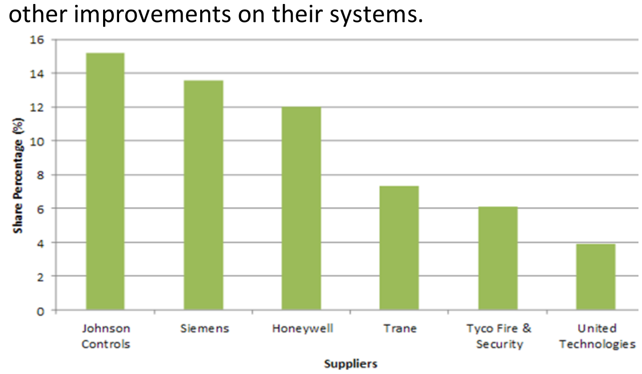

Figure 3 BMS Suppliers and Market share 2005

3.2 Fault detection and diagnosis potential of building management systems

A computer with supervisory and control software, as exists in most current BMSs, is capable of providing feedback on system operations, energy consumption and fault detection. Normally the software provides a number of distinct components that can be exploited for fault detection and diagnosis, including but not restricted to:

- Engineering/strategy configuration tool: This allows the user to set up strategies and program the outstations.
- Graphics software: Programmable graphic displays of plant operations with live point values that allow the BMS to be operated and monitored.
- Scheduling: Scheduling software is provided to allow the user to time-schedule plant.
- Data logging: The supervisory software provides a data-logging and archiving component.
- Reports: A routine and an alarm-reporting component is provided.
- User configuration and security: Remote access and level of access may be configured.

- The software used to control building energy management systems may gather data from a variety of information sources. They will typically measure temperature changes, humidity levels, occupancy patterns and energy use. Many energy control systems also measure air quality and carbon dioxide levels to help maintain healthy buildings.
- The resultant data is then analysed through the use of visualisation and statistical software tools. Issues with the operation of building components and opportunities for possible retrofit or operational changes can be identified using these tools.

Several articles to date prescribe the use of the monitoring capabilities of a BMS to monitor how energy is used in a building and to identify Energy Conservation Measures (ECMs) [11]. Numerous published case studies also quantify significant savings were identified using data acquired from BMS [12][13][14][15][16][17] However several issues are commonly encountered performing these activities as is explained in 3.3.

3.3 Key points of the building management systems for automated fault detection and diagnostics, what is now and what should be done

Based on the experiences of the IRUSE Galway research group, some of the common issues encountered in BMS deployments in real buildings relating to their specification, installation are briefly mentioned. These issues were mainly documented by Paul Raftery and published in the proceeding of the Clima2010 – 10th REHVA World Congress [18] and relate to: measurement framework, electrical panel layouts, visualisation and analysis software, 'Value engineering', data quality and personnel resources. Even resolving these issues, although the BMS technology, standards and guidelines at the overall management level are available, looking closely at building energy management it is possible to observe that buildings rarely perform as well in practice as they should be according to design estimation. There are many reasons for this, including improper equipment selection and installation, lack of rigorous commissioning and proper maintenance, and poor feedback on operational performance, including energy performance. All these issues justify the need and give the focus to a project like CASCADE. In order to provide with a robust and reliable fault detection and diagnosis platform some key point must be studied so the FDD tools can be seemingly incorporated into BMS. Among these key points we have:

- Sensors: availability and localization
- Visualization: raw data, scatter plots, carpet plots…
- Data transfer and storage: wired/wireless; csv, mysql, MS Access, etc.
- Sensors/Actuators communication protocols: Open source, proprietary
- Possibility to incorporate new 'ad-hoc' modules
- Possibility to define control actions, define alarms to include FDD rules

Another, non-technical key point should also be taken into account and/or addressed, among them we find:

- Experience of personnel with the system
- Customizability of the implemented solution
- Usability of the system
- Standardization of the approach
- Security firewalls from airport and manufacturer
- Reliability and calibration of the system
- Suitability of data for FDD

These key points form the basis to perform the SWOT analysis framework aiming at verifying the suitability of an installed BMS system to incorporate the fault detection and diagnosis solution developed by the CASCADE project. In section 4 this CASCADE SWOT framework and methodology will be further discussed and explained in detail after giving an outlook on the future of BMS technology.

3.4 Envisioned improved BMS: integrated automated fault detection and diagnostics

With the increasing needs of the building management market, and the current deficit of highly skilled personnel time in the area, a drive towards a more advanced suite of building automation systems is in place. There is a need for greater visibility of energy consumption and this in turn pressurises evolution of skill sets and knowledge required by facility personnel. Current research within industry asserts that a building facilities manager's job has become increasingly complex due to the multi-disciplinary requirements. This leads to a conclusion that it may prove difficult to find appropriate personnel to fully utilize the advantages brought by modern BMS. Thus, current thinking points towards bridging this knowledge gap by embedding intelligence and knowledge in the BMS system itself. Previously building management personnel must be trained to interpret building performance data generated by the BMS . New advances in artificial intelligence incorporated in an automated fault detection and diagnosis suite within the BMS will provide a systematic break-down of the problems occurring, and through 'knowledge' gained from previous similar faults, will be able to offer advice to personnel. This will greatly reduce both workload of current staff, and training time of future staff.

Another important trend is that of protocols. Currently Building management systems communications are governed by protocols such as BACnet and LonWorks. These systems are now being fitted with Internet protocols capability, which allows them to "utilize the same protocols and infrastructure equipment as the IT network".

As we move towards high-tech we must also understand information provided as we gain access to a great deal of buildings. With this, the complexity of the facilities manager's job increases as it is also encompassing managing the building's information technology systems. Facilities managers will wholly fit these demanding criteria and in the future BMS understanding the technology employed to control the building and being able to interpret and act on the rich information provided by future BMS. For the time being, a rule-based control and management system can be used to bridge this skill shortage by integrating expert's intelligence into the BMS.

There is currently a great deal of interest in artificial intelligence (AI) technologies and in many areas it is now moving out of the research laboratories into practical applications. Knowledge-based systems (KBS) are one form of AI where knowledge is captured from experts and stored, for example using a particular ontology. A KBS can access the knowledge-base to diagnose the problem and suggest the best course of action in each case. An intelligent building control system, with a KBS reacting to information fed from the various control sensors in the building, is now a possibility.

To be practical, a rule-based building control and management system must be designed in such a way that the knowledge, coded as rules, is independent of the building configuration with an object-oriented approach for the systems. The rules must operate on the data and information types within description which are consistent knowledge-based of any one of the building defined classes. However static knowledge-based control and management won't be enough in the future intelligent building. The ability to learn from past behaviour must be introduced to the system so the robustness of the systems is increased and ensured during the whole life-cycle of the building operation.

Most BMS systems provide data on building equipment and it's up to an engineer to analyse and interpret the data. Regardless of how talented or knowledgeable the engineer maybe it's better if a software application can support the engineer or technician in the analysis. That is why one of the emerging software applications especially for large HVAC systems is fault detection and diagnostics (FDD) and predictive analytics. These tools generally support the optimization of the HVAC system and can result in significant energy and cost savings

Build A Wide-Ranging Suite Of Energy Applications – This may be the greatest undertaking for the BMS manufacturers. It's much more than just presenting energy consumption and cost data and deriving trends in usage. It involves complete interoperability with the grid, renewable energy sources, storage and opportunities we envision with a smart grids and smart buildings. One such application would be an 'Automated Demand Response' – Users will need a software application that can activate predefined electrical load reducing signals to the HVAC, lighting and power management systems and do so based on different levels of load reduction. This will require development of the scenarios for different responses, measurement and verification of results, and tracking of financial effects.

3.5 Comparison between existing and emerging BMS

There are many levels to compare BMS systems on. It is important to note that no one system fits all needs. The market has many key players who offer vastly different suites according to customer's needs. Indeed, many buildings require a multi-faceted approach which is best served by suites provided by a number of system vendors working under a centralised approach. For example a centralised BMS system with Siemens security, Honeywell HVAC systems and sensors and a third vendor for fire safety. Further to this, Building managers information' scope has widened exponentially in the last 10 years, and now incorporates financial data, weather data and energy consumption alongside more traditional BMS data. Users need to see the financial data, costs and budgets associated with the energy consumption. They need the ability to compare weather data with energy costs in that period. There is a need to structure and display data in a move towards integration of data silos. These BMS systems will require a tool which allows standardized data from a variety of sources to be implemented in an open database structure. This Integration of systems requires an attachment of meaning or 'semantics' to the data to allow users to derive more functionality from the centralised system structure. Therefore, interoperability is imperative.

4. SWOT ANALYSIS FOR EVALUATING BMS POTENTIAL TO SUPPORT FDD

In this section a brief introduction into what a SWOT analysis stands for is presented followed by a description on how this management tool will be used to identify the readiness of the facility for the implementation of the CASCADE solution.

The SWOT analysis is the core of the BMS assessment which is part of the initiation phase of the CASCADE solution application. The SWOT analysis will also help to identify where FDD can have the biggest impact within the HVAC system once the CASCADE solution is in place. It is expected that FDD will have a great impact in the reduction of energy consumption thanks to the isolation and addressing of the faulty operation modes allowing for a validation of the energy savings in compliance and support to the ISO 50001 requirements. The reduction on energy consumption also feeds back into the business model reducing the time for return of invest after the implementation of the CASCADE solution. Other identified impacts are related to comfort and indoor air quality as well as equipment maintenance and equipment life. FDD in the way it will be carried out will be able to produce quantifiable targets for each action / fault that is detected and addressed.

4.1 SWOT analysis and framework

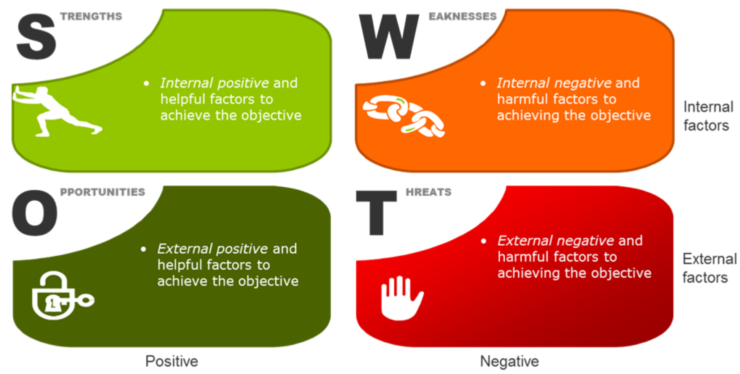

Figure 4 SWOT analysis diagram

A SWOT analysis is a useful technique to spot and understand the four aspect of a project of business for which the acronym stands for. It helps identifying internal and external factors that can be favourable or unfavourable to achieve the objectives proposed. In Figure 4 a descriptive graph of the SWOT analysis is presented and in the following paragraphs and section how a SWOT analysis is to be applied in the context of the CASCADE framework is presented and discussed.

Figure 5 shows the proposed framework for performing the SWOT analysis. The approach proposed to follow two parallel routes, one for identifying strengths and weaknesses and other for spotting opportunities and threads, at the end of which the results will be combined into the assembled SWOT analysis.

- **Strengths and Weaknesses:**
  - First the key ICT elements of the BMS need to be identified;
  - Second a checklist in form of a league table is to be applied to the ICT part of the BMS;
  - Following the results from this checklist are to be analysed and conclusions will be drawn in the form of lists of Strengths and Weaknesses;
  - The weaknesses of the system will need to be addressed to fully apply the CASCADE framework in the facility
- **Opportunities and threads:** the procedures is similar to the one for Strengths and Weaknesses:
  - First the key personnel operating the BMS in the facility needs to be identified;
  - Afterwards a questionnaire must be done on this key personnel;
  - Conclusions from the questionnaire will form the list of Opportunities an threads.

The ideal IT situation for the CASCDE implementation can be seen on Table 1. On this table we present the key list to be applied on the facilities in comparison with the BMS development technology in terms of possible Strengths and Weaknesses. The ideal situation for CASCADE is to have the BMS with the feature outlined in Table1 column “Ideal BMS for CASCADE”. For this reason we once the checklist is implemented in the facility we can consider the following:

- Every key point already in the “ideal” range is considered an **Strength**;
- Every key point below the range of “ideal” is considered a **Weakness** and should be addressed promptly; if this is not possible then it should also become a **Thread**;
- Every key point above the range of the “ideal” will be considered as an **Strength** to be relied on and actions should be scheduled to fully exploit it in the particular implementation of the CASCADE solution for that facility;
- Every key point which status can’t be established should be marked as a **Thread** and steps should be scheduled to clarify the status and to be able to identify what it will represent in the CASCADE solution.

With regard the **Opportunities and Threads**, on Table 3 it is presented a questionnaire to be implemented on the identified key personal for the management, operation and maintenance of the BMS. Results from this questionnaire are to be analysed on a case to case basis to determine the Opportunities and Threads of the installed systems. However as a guideline some threatening scenarios can be:

- Any recent or near future change in key personnel due to the entropy and possible lack of experience it brings to the team;
- Any difficulty or lack of functionality in the interaction with the BMS GUI since it augment the effort to perform the tasks and reduction of the possibility to personalise reports and implement ideas;
- Old equipment, long time between calibrations and maintenance operations, system providing false

positives, are threatening because it greatly reduces the reliability of the system;

- Others will become clear once the questionnaire is answered by the personnel.

4.2 General recommendations

General recommendations are a set of best-practice actions to be checked on each facility that will enhance the application of the CASCADE solution on the facility. This list will ensure that local regulations and industry standards are being followed prior and after the application of the CASCADE framework. Some best-practice actions are presented next:

- Gather local regulatory information on air quality and comfort.
- Gather standards applied during construction and commissioning phases.
- Check that set-points and schedules correspond with those on regulations and standards and plan actions to adjust if necessary.
- Creation, if not already in place, of a cloud based of physical based SQL database to store BMS data.
- Set up of automated and periodic back up of data.
- Set up secure and possibly remote access to database.
- Ensure logging and completeness of data-base data.

Following the general recommendations will ensure, not only the best application of the CASCADE solution but also will help to monitor and maintain the whole system both, locally and remotely while providing easy to access data for future necessities.

4.3 Checklist of key points for BMS

Next the key points used to perform the **strengths** and **weaknesses** of the SWOT of the BMS for FDD application in the pilot facilities is presented below in Table 1 with the top level points to investigate a possibly address for a fully and successful CASCADE-FDD implementation. Next some of the meanings the items in the table are explained. In relation to being **open source** the following aspects are considered:

- BMS Code Accessible: to understand internal functioning of the BMS, control actions and rules
- Control software modifiable: possibility to implement ad-hoc control functions within the BMS and/or embedded software into the controller
- Scripting language interaction with BMS: possibility to communicate with the BMS in other way than the Graphical User Interface to read values and set parameters (this will allow further automation of the system)

Being **extensible** is analysed as follow:

- Manufacturer SW/HW modules: the manufacturer provides the software / hardware modules to enhance capabilities of the BMS
- Ad-hoc SW/HW modules: the manufacturer provides an infrastructure to attach new, ad-hoc, modules to the system

Sensors are analysed in relation to their degree of accuracy of the sensors (Table 2) and their robustness which is intended as the likelihood of the sensor to give an erroneous reading (this can be the effect of either a physical problem, a calibration problem or a connection problem)

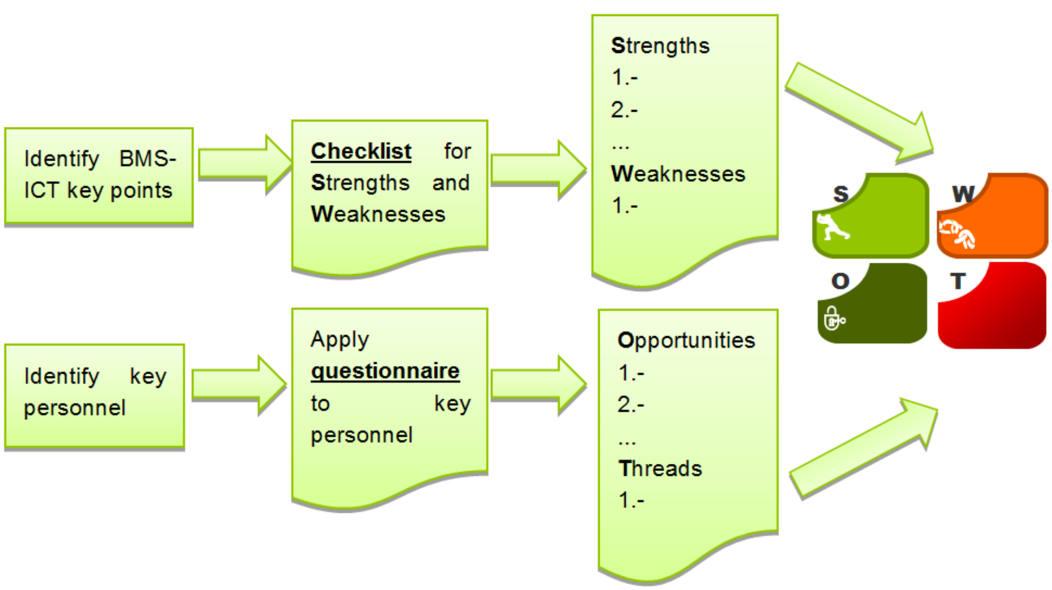

Table 1 Strengths and Weaknesses of BMS and their evolution

System Characteristics	Key questions	Basic BMS solution	Most diffuse BMS solution	Ideal BMS for CASCADE	BMS of the Future
BMS basics	Manufacturer				
	Model				
	Systems under BMS	(HVAC, lighting, IT, access control, water, fire system, etc.)			
	Variables controlled by the BMS	(Air temperature, air humidity, water system temperature, lighting levels, fans/pumps speed, etc.)			
	Main key performance indicators used	None	Comfort conditions on conditioned areas Utility bills	+ detailed energy consumption	+ Multifaclity detailed energy and emissions management
	Weather station?	None	Temperature / Humidity measured by BMS	Full weather station installed on-site	Full high resolution and accurate weather station installed on site and live link with weather forecast
Open-Source	BMS code accessible			●	●
	Controller software modifiable			●	●
	Scripting language interaction with BMS			●	●
Extensible	Manufacturer SW/HW modules/elements		●		
	Ad-hoc SW/HW modules/elements			●	●
Sensors	Sensors Accuracy	Low	Average	High	High
	Sensors Robustness	Low	Low	High	High
Data available for FDD	Data points	None	Controlled Variables	+ control signals	Ubiquitous
	Data frequency	None	>15 minutes	Minute	< Minute
	Data visualization	None	Trends	Plots	Configurable Plots
	Data Accuracy	No data	Poor	High	High
	Data base availability and access	No database	Manual	Automated / Reading Access	Automated / Full External Access
Communication protocols	Field level (BACnet, LonWorks, Modbus, M-bus)	Ad-hoc	Proprietary/Open	BACnet, Modbus, M-Bus,	tbd
	Data transfer level (Ethernet, RS-232, Wireless)	RS-232	RS-232/Ethernet	RS-232/Ethernet	tbd
	Data content level (csv, xml)	No data	txt/csv	xml	tbd
Service Level	System	●	●	●	●
	Facility		●	●	●
	Facility + Grid			●	●
	Multi-facility				●

Table 2 Questions to support Opportunities and Threads identification

Type of sensor	Low accuracy	Average accuracy	High accuracy
Temperature	> 1°C	+/- 1°C	+/- 0,1 °C
Humidity	+/- 5 %	+/- 2 %	+/- 1 %
Volume flow (air)	> 5 %	+/- 5 %	+/- 1 %
Volume flow (water)	+/- 5 %	+/- 2 %	+/- 1 %
Electric power	+/- 1 %	+/- 0,5 %	+/- 0,1 %
Light meter	+/- 10%	+/- 5 %	+/- 1%

Data availability is investigated according to:

- Data points: are we measuring the right variables? Is their location optimal? Are we logging the values and storing them? For these questions we consider both controlled variables and control signals;
- Data frequency: is the measuring frequency apt for FDD: Low (higer than 15 minutes), Average (between 1 minute and 15 minutes) or High (one minute or less)?
- Data visualization: is there any kind of visualization available in the BMS, if so what types? Trending, scatter plots, carpet plots, etc.
- Data accuracy: direct relationship with Sensor Accuracy plus verification of te consistency of measurement location.
- Data base availability and access: does the database exist? How can it be accessed?

Communication protocols are also studied at the different levels field level, data transfer level and Field level (BACnet, LonWorks, Modbus, M-bus), Data transfer level (Ethernet, RS-232, Wireless) , Data content level (csv, xml) which focuses on how is the content in the data structured. For example: csv is useful but xml is much richer for quering and data transferring. Finally the service level: at what level are the services being provided by the BMS manufacturer to the Facility:

- System: only contolling/maintaining/optimising the individual system (HVAC, Lighting, One Area of the facility)
- Facility level: managing the whole facility and optimising functioning of each system to improve the overall performance of the facility:
- Facility + Grid: same as facility plus optimising energy exchange withy the grid for reducing costs/consumptions and emissions.
- Multi-facility: possibility to manage multiple facilities at sector, district, national or international level.

The checklist can be completed after the ICT characterization of the systems and taking into account documentation from the airport that will support the information to be provided in the list. However this implementation for the strengths and weaknesses of the SWOT should be done on a case-to-case basis since the systems installed on the facilities must comply with particular needs and no standard solution exists for all the implementations. Table 1 shows thr structure of the checklist and how the technical BMS evolution compares against these features.

4.4 Questionnaire to be used to interview key personnel in order to spot opportunities and threads for the SWOT analysis

Opportunities and threads of the SWOT analysis are external and normally non-technical factors that can be extracted from interaction with key personal managing the facility. In this light a questionnaire (Table 3) has been prepared to be able to collect the necessary information from these key personnel that can be further analysed to extract OT.

Table 3 Questions to support Opportunities and Threads identification

BMS interaction	Usability of the GUI of the BMS
	What difficulties in interaction with BMS have been encountered so far?
	How could interaction with BMS be improved? (adding new features or improvement old one)
	What type of report can be generated from BMS? (Excel sheets, full report diagrams, only text files, cost benefit analysis, yearly trends…)
	Can the report be modified to include/exclude features like KPI?
	Who is the receiver of the report?
BMS operation	When was the BMS installed?
	When was the last control/calibration of the system performed?
	How many false-positive and false-negative faults the system reports per year?
	What are the more common faults detected by the BMS?

Energy management	Which plants are controlled/monitored by the BMS?
	What types of key performance indicators are being used?
	Is information about number of passengers being recorded? Can this information be included in the KPI?
	Is there any report used for energy management?
	Is the system useful for addressing Building's Energy Efficiency? Why?
	What feature would you add to the system to address energy efficiency?

5. CONCLUSION AND FUTURE WORK

This paper presents a research work carried out under the umbrella of the CASCADE FP7 EU research project, which is developing facility-specific measurement-based energy action plans for the airport energy managers that are underpinned by Fault Detection Diagnosis (FDD). The paper starts with an overview of the project. Section 3 focuses on Building Management Systems, starting from an overview of the current state of the art of this technology, the BMS potential to support FDD, and an outlook on expected future development of BMS. Section 3 outlines the Key points for analysing Building Management Systems to study their potential for supporting automated fault detection and diagnostics showing how they are and what should be done. These key points are then used in section 4 where a detailed a comprehensive Strengths Weakness Opportunity and Treads (SWOT) framework that aims at verifying the suitability of an installed BMS system to incorporate the fault detection and diagnosis tools. The proposed SWOT analysis framework stands on a checklist that focus on BMS technical aspects to identify Strength and Weaknesses and on a questionnaire on the BMS use to identify opportunities and threads.

As part of the future work, we will apply this framework to the two pilots of the CASCADE project which are two important European airports Roma Fiumicino (FCO) and SEA Malpensa (MXP).

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