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Industry 4.0 Driven Result-oriented PSS: An Assessment in the Energy Management

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ABSTRACT

Sustainability is a current challenge and all sectors, including the buildings one, are being called upon to provide a solution to mitigate climate change. The state of the art of energy management using Information and Communication Technologies (ICT) technology in building systems industry is characterized by a traditional monitoring approach which could assess the energy consumption of the building but that cannot manage and act the required action to improve the energy management according to a demand side approach. The aim of this paper is to overcome this traditional monitoring approach, presenting Simon, a new model proposed by Evogy, enabling a result-oriented product service system (PSS) for buildings through cyber-physical systems, artificial intelligence, and internet of things adoption. The main findings highlight the benefits associated with the Simon model by virtue of digital-based predictive maintenance on the real system. In addition, its adoption allows the PSS provider to aggregate energy demand from the plethora of buildings and, according to digital technologies, not only monitor consumption but also implement equipment. Finally, the application case highlights the benefits are different and thus stands as a best practice for combining sustainability and digitization.

Keywords: Product-Service Systems, Cyber-Physical System, Energy Management, Smart Building, Result-oriented PSS, Industry 4.0
JEL Classifications: O12, O14, O33, Q40

1. INTRODUCTION

Nowadays, product-service systems (PSSs) (Goedkoop et al., 1999) and digital technologies, grouped under the umbrella of Industry 4.0 (I4.0) (Roblek et al., 2016), represent valuable business opportunities to enhance companies' competitiveness (Kowalkowski et al., 2017; Porter et al., 2014; World Economic Forum, 2016). From one side, PSSs can enable companies to provide to the customers several types of additional services to be embedded and integrated with the physical product (Tukker, 2004) through a suitable design process (Sassanelli and Pezzotta, 2019). From the other side, digital technologies can play a strategic role in the exploitation of the data and knowledge deriving by the provision of these new services and strengthen the value proposition given by PSSs providers (Coreynen et al., 2017; Sassanelli et al., 2019). In particular, a multi-criteria framework (D'Adamo et al., 2021), which includes customer factors within supplier selection, can play a key role in enterprise supply chain management (Vacchi et al., 2021).

However, the employment of such business models and technologies can often meet several hurdles (Niebles-Nunez et al., 2022), mainly in the case of SMEs companies (Ambroise et al., 2018). Sustainability and associated concepts, such as the green-circular premium, are having a major impact on the manufacturing industry (Appolloni et al., 2022), but more broadly on new identifications of added value within the business system (Nugraha et al., 2019).

The main barriers against the transition from traditional businesses, based on the design and sale of physical products, to a new business orientation, which comprises an integrated combination of products and services (Kowalkowski et al., 2015; Neely, 2008), were detected in user acceptance and radical shifts in business culture (Schotman et al., 2014). Financial, organizational and cultural aspects can also contribute to lead companies towards the service paradox (Brax, 2005; Gebauer et al., 2005). Moreover, the lack of adequate technical expertise and specialist knowledge are relevant gaps in the digital technology application domain (Acerbi et al., 2022; Sassanelli et al., 2020). Last, a set of boundary issues (e.g., always changing customer expectations, cultural transformation, updated regulations and skills, etc.) contribute to hamper both the servitization and digital transitions (Baines et al., 2007; World Economic Forum, 2016). In addition, organizational models are not always able to combine sustainable needs with value chain flexibility concepts (Dwivedi et al., 2021). The resilience of a system is a winning element to face the post-pandemic recovery (Arribas-Ibar et al., 2021).

Companies managers and government leaders need to manage these challenges to reveal and make exploitable the set of benefits that digital technologies offer to both society and industry (Rehman et al., 2021; Rumbia et al., 2022). Indeed, to properly support the products upgrade, the process improvement and the business models adaptation to the digital age, several initiatives have been launched both at Europe and world level. Starting from 2013, have been launched the ICT Innovation for Manufacturing SMEs (I4MS) initiative, followed by the Smart Anything Everywhere (SAE) in 2015 (European Commission, 2018), belonging to the European Commission's Digitising European Industry (DEI) Strategy (European Commission, 2016), and by Digital Transformation of Industries (DTI), a project launched by the World Economic Forum in 2015 (World Economic Forum, 2016). The goal of these actions is to support the growth of Digital Innovation Hubs (DIH) to foster SMEs, start-ups and mid-caps to enhance their products and services through the inclusion of innovative digital technologies: user companies, in particular SMEs and mid-caps, needing both to invest in digital technologies and to include ever more services among their offerings to improve their competitiveness (Davies, 2004), are put in contact with supply companies (owning suitable ICT products helpful to satisfy the needs of the users). Both the inclusion in innovation and the sustainability of production and consumption are two major issues on which the literature places great emphasis (Schneider et al., 2021).

In this context, the adoption of digital technologies fosters the service innovation of manufacturers (Belhadi et al., 2021; Kindström et al., 2009). Through their deployment, companies can easily develop, implement and provide PSSs (especially result-oriented ones), renowned to play a strategic role to strengthen the company competitiveness, prolong the relationship between providers and customers, and shift the owning and operational responsibility of the solution on the provider (Baines et al., 2007; Lerch et al., 2015).

The literature places attention on the relationship between business models and the most common capabilities when developing Internet of Things (IoT)-based PSS referred to several sectors, including also the energy one (Karttunen et al., 2021). In fact, the energy management (EM) is called not only to identify solutions related to the implementation of green plants in residential sector (D'Adamo et al., 2022) but also to energy efficiency models in which both Artificial Intelligence (AI) (Yigitcanlar et al., 2021) and Cyber-Physical System (CPS) (Morella et al., 2020) can play a key role towards the efficiency of resources. In addition, other authors place relevance on the ability of PSS to combine market requirements and technology choices by proposing its application to a case study (Pereia Pessoa et al., 2022).

Following this approach, this paper aims to evaluate the role of digital technologies within EM in smart building systems. A new model (called 'Simon The digital energy specialist'), born from the collaboration between an SME and a university, is used to enable the delivery of a result-oriented PSS in the energy and residential sector through the adoption of different digital technologies, such as IoT, AI and CPS. The model development process are proposed through a pilot case and the relative benefits associated with its adoption are calculated.

This work is structured as follows. Section 2 introduces the research context, defining the EM industry and declining its application in PSS and I4.0. Section 3 reports a description of the methodology adopted to develop the model, also introducing the application case company. Section 4 explains the main result of the study, i.e., the Simon model, and its application on a selected pilot application case. Finally, Section 5 is dedicated to results discussion and Section 6 concludes the paper, triangulating results with theory and providing further researches and limitations.

2. RESEARCH CONTEXT: ENERGY MANAGEMENT IN PSS AND I4.0 CONTEXTS

In literature, digital technologies' role to ease the service innovation of manufacturers is renowned (Lerch et al., 2015). In particular, three digital technologies (Internet of things, cloud computing and predictive analytics) have been detected to support knowledge generation, from collection and transmission of data up to storing, aggregation and processing (Ardolino et al., 2016), upon which companies can deploy advanced product-service solutions. Generally, smart technologies enable four different levels of products capabilities (monitoring, control, optimization, autonomy), each one building on the preceding ones (Porter et al., 2014), and trigger a wide bundle of services whose delivery is strictly related to the physical products (leading to the provision of new and more efficient result-oriented PSSs) (Gaiardelli et al., 2014).

Traditionally, the market of energy in the buildings and residential sector is seen as a 'necessary evil' and not a core activity for building management and maintenance. The state of the art of EM using ICT technology in the building industry is characterized by a traditional monitoring approach (Clarke et al., 2002) which could assess the energy consumption of the building but that cannot manage and do the required action to improve the EM according to a demand side approach (Yoon et al., 2014). Therefore, EM context needs a support of digital technologies, especially in residential and civil industry (Francisco et al., 2020). On one side, the large enterprises are well served since EM is one of the core processes of the company also in terms of cost and criticality on process performances. On the other side, there is a plethora of SMEs in particular in buildings and civil market (real estate, buildings, residential, etc.) in which it is not possible to exploit the competences and the leverage used in the large enterprises. Anyway, due to the high responsibilities of these sectors on the pollution and also to the opportunity to save energy and money optimizing the consumption based on a demand-side management approach (Mariano-Hernández et al., 2021), there is the need to optimize the energy consumption in this market (Pierce et al., 2017). Heating, ventilation, and air conditioning (HVAC) systems unveiled to be strategic to manage to address this scope in all kind of buildings (e.g., non-domestic and office buildings) (Zhao et al., 2021), even simulating the operation of specific components (general electric system, heat pump, air handling unit) (Pirouz et al., 2021). Ahmad et al. (2016) provided a classification of metering and monitoring devices and selected the sensing solutions suitable to improve and digitize such systems. However, this is not enough, since according to Masoso and Grobler (2010) waste energy from poor occupants' behaviour warrant more serious attention and (Roccotelli et al., 2021) also highlighted the impact of window operation on building energy consumption.

Indeed, recent researches demonstrate that relevant energy savings can be registered through the adoption of smart technologies in the buildings and civil industry. It has been proved that energy efficiency from buildings has led to 5-6% reduction of EU energy consumption (European Commission, 2017b, 2017a). The potential of data, made available through I4.0 technologies employment in smart buildings, is strategic to shrink greenhouse gas emissions (Zuo et al., 2013). Smart building play a strategic role mainly in energy efficiency improvement (with 60% saving of lighting energy and 5-15% of HVAC energy) (European Commission, 2017b), also contributing to both safety and security efficiency and employee productivity enhancement. As a consequence, in the last years, several approaches were proposed in literature for the building industry to model thermal dynamics (Hong et al., 2019) and estimate building energy consumption (Guo et al., 2021) or detect and predict occupancy heat emissions (Tien et al., 2020). In particular, Villa and Sassanelli (2020) proposed a literature review of the extant models for estimating in a dynamic way the interior temperature of a building and proposed a data-driven black box predictive model to fully exploit smart capabilities.

3. RESEARCH METHODOLOGY AND THE APPLICATION CASE

This section is divided in two parts. In the first one the model is described (section 3.1) and in the second one the application case is presented (section 3.2). Finally, is conducted a survey that involved all partners of the project (section 3.3).

3.1. The Description of the Model

'Simon the digital energy specialist' (from now on Simon) model is based on the data-driven black box modelling approach (Villa et al., 2020). It has been developed by *Evogy srl*, an Italian SME specialized in EM. To boost and accelerate digital technology adoption (of both AI algorithms and the CPS-integrated platform and software), *Evogy srl* collaborates with the Italian *Politecnico di Milano*'s DIH (Sassanelli et al., 2022). The research methodology implemented has been structured based on several joint research traditions. Indeed, it calls out principles from interpretative (Williamson, 2002), interactive (Svensson et al., 2007) and system development (Nunamaker Jr. et al., 1990), keeping as main reference the design research methodology (DRM) framework (Blessing et al., 2009). The proposed research methodology (inspired and based on [Sassanelli and Pezzotta, 2019]) is based on three main phases: 1. Observation and conceptualization, 2. Theory Building and Model Development, 3. Validation. It guided stakeholders to conceptualize and develop the SIMON model in order to enable the provision of result-oriented-PSS in the smart building industry through the embedding of digital technologies. Through the use of an EMS (Energy Management System) platform based on IoT/AI technology, Evogy provides solutions and services aimed at the management and optimization of energy consumption for Customers of the Industry 4.0 market, smart buildings and the multisite Retail market. The customers are different: from large enterprises, who consider EM a core process and don't want to share data, up to SMEs that in particular in building civil market (real estate, buildings, residentials, etc.) are not able to exploit the competences and the leverage used in the large enterprises. This issue, especially coming from SMEs belonging to the buildings and civil industry, together with results of both state of the art and practice, pushed *Evogy srl* to the development of SIMON model and the introduction of ICT technologies support. The third phase, validation, has been conducted through a pilot application case in a building of a highly specialized hospital group in Milan area. In this application case, first the full Simon infrastructure has been installed in the building. This was required to proceed with a two-step phase: the delivery of the monitoring/analysis services for efficiency measures and the remote control and automatized services. Furthermore, the switch to the remote control and automatized level on the entire building through the centralized EMS platform (that is already enabled through the Simon model thanks to the IoT infrastructure but still not used) has also enabled in a third phase the delivery of COVID-driven services.

3.2. The Case: Humanitas Hospital in Milan

Humanitas Medical Care is the network of Humanitas medical centres, one of the largest and most consolidated companies on the Italian healthcare field, in terms of quality of treatment paths, professionals and installed technologies. These centres cover the whole set of specialist clinics and offer dedicated and prevention-oriented pathways for women, men, children, elderly and athletes using teams of experts coming mainly from local hospitals and most modern diagnostic technologies. The Humanitas Medical Care network also includes several sampling points, scattered throughout the territory, easy to reach, which patients can access for analysis certified by the Humanitas Laboratory, both in agreement with the S.S.N. (*Servizio Sanitario Nazionale*) and privately, enjoying reduced waiting times. To be ever closer to people, both the clinics and the pick-up points are located in strategic areas, which are well served by public transport or inside business areas, such as the pilot test chosen to adopt Simon, "Il Fiordaliso".

The case of Humanitas enlightens how the services are actually enacted in a real case, leading to savings obtained thanks to the adoption of digital and servitized solutions. The services provided by Evogy to Humanitas through the implementation of Simon were gradually enabled along a five-step path (Table 1). Along this, the company was able to strengthen its relation with the customer, win his trust and progressively install and adopt different digital technologies in the building.

3.3. Survey

The final step in the work is to understand the managerial implications from the project partners and their professional contacts. High management profiles with a consistent number of years of experience (about 10) have been identified. The number of experts is equal to 6 and for each one interviews were conducted in two steps. The interviews took place in person and both steps lasted about 1 h. In the first, the results were presented, explained and reviewed. In the second, however, more extensive reflections were made in order to capture future directions of analysis.

4. RESULTS

This section is composed of three main parts. In the first, the Simon model is introduced. In the second one, how the EM system has been actually implemented on the pilot case is explained, detailing the phases of engagement, inspection and commissioning with the customer. Finally, in the third part, the monitoring and control phases bring evidence of the results obtained through the implementation of the system on the pilot building.

4.1. The Simon Model

This sub-section is aimed at presenting both characteristics and properties of the Simon model. Its approach is inspired by a butler who helps in the efficient and optimized management of a system (in this specific case, energy management of smart buildings). Within Simon model, three main technologies (IoT, CPS and AI) have been considered, systematized and embedded (Figure 1):

1. Simon on the field (IoT systems embedded on the existing devices): a control board gathers data coming from a supporting data metering and transmission infrastructure (i.e. co-generator, sensors and field meters, photovoltaic (PV) systems, Programmable Logic Controller (PLC), Building Management System). Indeed, it is necessary to equip with sensors and hardware the building plants in order to activate the required action to optimize the global EM portfolio;
2. Simon Lab (directly linked to the CPS of the equipment/buildings controlled): it includes also the simulation of the building, to take into account customer constraints such as people comfort in the environment;
3. AI: algorithms interacting with the Simon Lab to capture and replicate the operators' competence to optimize the EM.

Table 1: Simon's adoption path

Phase number	Phase	Time horizon
1	Engagement phase	-
2	Inspections and price quotation	Around 1 week
3	Hardware procurement System installation and commissioning (enabling the monitoring phase)	Around 1 week 2 h
4	Data monitoring and gathering to set-up the system (triggering the first corrections of anomalies and maintainer's bad management of the system)	3 months
5	System control phase and service provided in cloud in "pay as you go" way.	-

Simon is organized into hierarchical levels to manage systems in multi-site configuration:

1. "Project" layer: the most aggregate level of information display. The human-machine interface is particularly important since this is the presentation layer of the aggregate consumption;
2. "Plant" layer: individual site or plant level;
3. "Device" layer: in this level it is represented the CPS, being possible to log into a virtual representation of each single component of the system.;
4. "Data-point" layer: single elementary information level (e.g. multi-meter consumption value, set-point, alarm);
5. "Security" layer: this layer is responsible for data security.

Each layer is characterized by specific features and mutually contribute to each of them:

1. The plants geolocation on maps with digitized building planimetry;
2. A customized dashboard with graphic widgets that can display KPIs, Energy Performance Indicators (EnPIs) or other aggregation layers of the obtained information;
3. Reports creation (on demand and/or with time planning) based on the user's template;
4. Alarm management with trigger and notification rules based on role/user;
5. Commands in ON/OFF or set point format, persistent or with duration according to CPS signals;
6. Commands in single and aggregate form (per plant areas, areas or floors), with and without time schedules and management of exceptional events;
7. Advanced data analysis and model construction (consumption, forecasting based on CPS model) to optimize the plant management and consumption/expense balance by referring to a baseline agreed and loaded on the platform;
8. Demand Response mode for balance grid congestion and electricity network services. It consists in creating real Virtual Power Pools (VPPs) of plants that, individually, could not participate in the electricity services market, but which, aggregated in clusters, can be used to intercept economic advantages both in terms of power (i.e. incentives for the capacity made available) and of energy (i.e. power supplied in the period of time necessary to solve network's critical issues). The aggregation function takes advantage of the regulatory changes introduced in Italy by the energy authority (*Autorità di Regolazione per Energia Reti e Ambiente - ARERA*) and

implemented by the operator of the electricity transmission grid (*Terna spa*).

Simon's functionalities are divided into two parts: Simon Buildings and Simon Industrial. In particular, the Simon building platform is mainly employed in the tertiary sector. It works through a series of sensors, which measure the environmental comfort (lux, temperature, RH, CO_2, etc.) by real-time monitoring and they also allow dynamic remote control of assets and facilities, reaching potential energy savings of between 20% and 40%. Thanks to this system, it is possible to have constant control of room comfort, an efficient air quality control by optimizing the hourly air exchange, dynamic load optimization and monthly reports on satisfaction and consumption trends. Moving to its interface, it has web-based systems accessible through App from smartphone or tablet or PC and a ticketing system for requests from/to the site and an alert system for ordinary and extraordinary maintenance interventions.

Figure 2 shows all components required and how they interact. The gateway, which is Niagara or a router, is the core of data collection from the field. It interfaces to a PLC, such as a field automation system, which communicates with the Building Management System (BMS). It is associated with equipment units like chillers, heat pumps or all control systems linked to the cooling and heating of the building. Furthermore, while signals go from the gateway to the equipment units during the control phase, the opposite occurs when data are read; consequently, signals are always bidirectional. Moreover, the measurement of variables, such as CO_2, temperature, power meter, happens through sensors placed in various parts of the building. However, in this case, signals go only to the gateway because they are typically in read mode. Then, if a write signal is needed, like an ON/OFF of devices, an actuator is fixed. Finally, being Simon in Cloud, there is a router (the VPN), which allows sending data to SimonLab. Table 2 enlightens the connections among Simon's layers and the features characterizing them:

Moreover, in Table 3 each service provided through the Simon solution, enabled by the functionalities detected above, has been defined and linked to:

Figure 1: SIMON model, the functional scheme

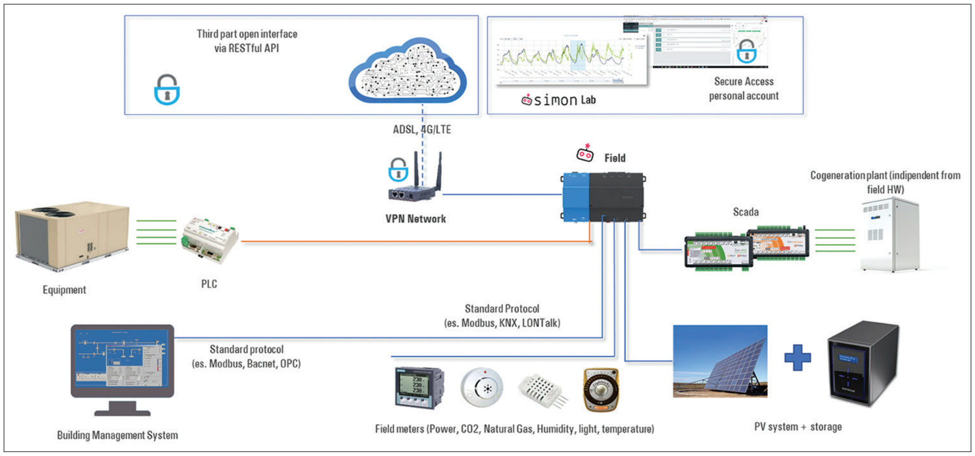


Figure 2: Functional diagram of simon buildings

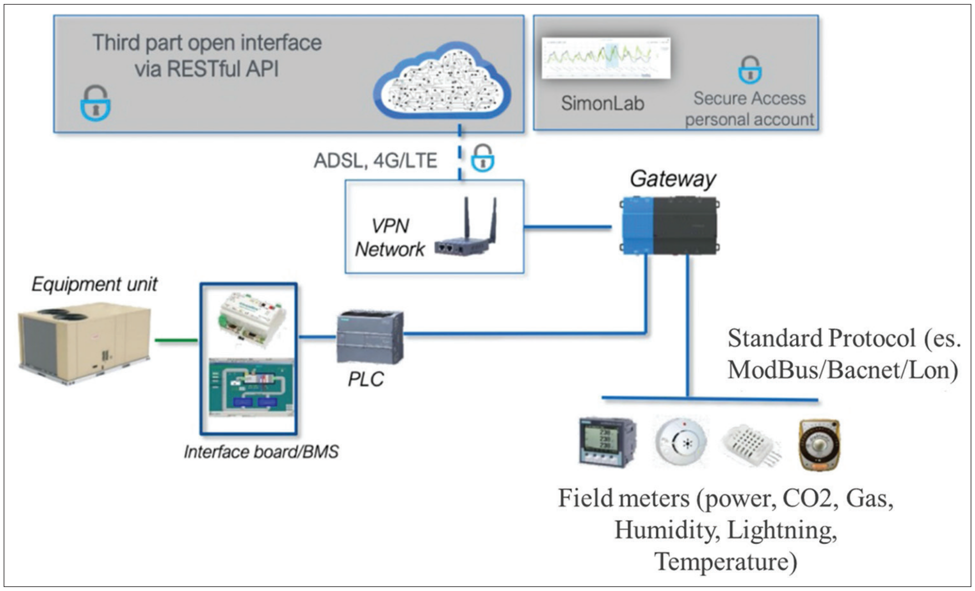


Table 2: Simon's layers and related characterizing features

Layer	Features							
	Plant geolocation	Dashboard with graphic widgets	Reports creation	Alarm management	Sending of commands	Commands in single and aggregate formats	Advanced data analytics and model construction	Grid congestion and electricity network services
Project		X	X	X		X	X	X
Plant	X	X	X	X	X	X	X	X
Device		X	X	X	X	X	X	X
Data-point		X	X	X	X			
Security		X		X				

Table 3: Digital technologies-based services: benefits for customer, service provider and TSO

Service delivered	Digital technology used			Smart capability enabled	Type of PSS enabled	Benefits for customer	Benefit for service provider	Benefits for transmission system operator (TSO)
	IoT	AI	CPS					
Consultancy on the modelling and design of the building infrastructure	-	-	-	-	Product-oriented	• Customized design of the system • Digitized building planimetry (CAD).	Complete knowledge of the building and of the system to be installed (BIM).	-
Installation/start-up and commissioning of the required technologies	X	-	X	-	Product-oriented	System installed and kick-off.	• Complete understanding of plants' issues; • Virtualization of the physical plants and virtual test of different models; • Availability of data for simulation analysis.	-
Plant geolocation	X	-	-	Monitoring	Product-oriented	Ease of geolocation in particular for multi-site plants.	Database of both projects and plants for remote monitoring of internal and external conditions.	Detection and mapping of existing plant for VPP definition and creation.
Diagnosis and reporting: dashboard and graphic features	X	X	X	Monitoring	Product-oriented	Customized KPIs, EnPIs and reports.	Continuous monitoring of the systems.	-
Help desk for product, process and business	X	-	X	Monitoring	Product-oriented	Remote and/or on-site assistance based on the gathered data.	Possibility to optimize assistance based on data gathered.	-
Updates/upgrades of HW and SW	X	X	-	Control	• Product-oriented • Result-oriented	Always updated EM system.	Possibility to upgrade the system based on the system monitoring leading to an easier achievement of target consumption results on contracts.	Possibility to activate Demand Response mode of plants thanks to updated/ upgraded HW and SW.
Remote control from centralized platform	X	-	X	Control	• Product-oriented • Result-oriented	• Personalization of the user experience and of the comfort level; • Plants control.	Remote control of system functions and reduced on-site interventions; Plant dynamic set-up.	-

(Contd...)

Table 3: ***(Continued)***

Service delivered	Digital technology used			Smart capability enabled	Type of PSS enabled	Benefits for customer	Benefit for service provider	Benefits for transmission system operator (TSO)
	IoT	AI	CPS					
Alarm management and sending of commands in single and aggregate formats	X	X	X	Control	• Product-oriented • Result-oriented	• Enabling of predictive diagnostics, service and repair; • System performances enhancement; • Plants shut-down avoidance; • Building environment discomfort avoidance.	• Reduced maintenance/ control interventions on-site; • Preventive maintenance.	-
Advanced data analytics and model construction and autonomous remote control of the entire building	X	X	X	Autonomy	Result-oriented	• Autonomous improvement of consumption and of the performance of energy systems; • Autonomous system personalization.	• Ordinary maintenance avoidance; • Knowledge of the entire operative life of the system; • Self-diagnosis and service; • Autonomous product operation; • Self-coordination of operation with other products and systems.	Real-time monitoring and possibility to activate Demand Response mode: dynamic plant management as a function of the electric grid balancing needs.
Demand Response mode for balanced grid congestion and electricity network services	X	X	X	Autonomy	Result-oriented	• Effective/efficient EM. • Possibility of creating real VPPs (Virtual Power Pools) of plants, to participate in the electricity services market and to intercept economic advantages both in terms of power and of energy.	Easier achievement of target consumption results on contracts.	• Balanced grid congestion; • Power and energy provision through VPPs in a dynamic economic way.

- The type of I4.0 technology (Rüßmann et al., 2015) used (IoT, AI, CPS);
- The smart capability enabled (monitoring, control, optimization, autonomy) (Porter et al., 2014);
- The type of PSS enabled (product-, use-, result-oriented) (Tukker, 2004);
- The benefits obtained through the specific service provided per each stakeholder (customer, PSS provider, Transmission System Operator [TSO]).

Indeed, Simon includes several services, e.g., the modelling and design of the building technological infrastructure, the installation of the required technologies up to the pro-active management of the building based on the data gathered and processed.

4.2. The Application Case: Engagement, Inspection and Commissioning

In this sub-section, the 5 steps presented in Table 1 are detailed for the application case conducted in the Humanitas hospital in Rozzano (Milan).

4.2.1. Engagement phase: Advantages expectations deriving from Simon's adoption

At the beginning of the engagement phase, in Simon only monitoring functionalities had been developed. Indeed, the control functionality still had to be developed and realized. Since the customer was very keen to pursue digital transformation, they accepted to be an early-adopter of the solution and test its full prototype. Indeed, Humanitas decided to adopt the solution since a valuable saving was envisaged through its adoption (3-5%).

At a first glance, in monitoring mode (still not implementing corrective control actions), the running of Simon can be already able to raise the bad functioning of the system analyzed. Indeed, most of the time, abnormalities happen in the system since the maintainer lacks of the continuous flow of information about the system functioning. Therefore, thanks to the monitoring phase done for Simon's setup on the system, there is a tendency to correct the bad management by the maintenance technician and obtain first savings.

Then, switching to the controlling phase, a further saving (around 8-9%) could be registered since Simon controls the system through the definition of a set-point, monitored and adjusted every 15 min. Therefore, wastes can be further reduced and the system use optimized, since without Simon the maintainer does not have data to set every 15 min and cannot be physically present 24/7. On this basis, Humanitas accepted to adopt Simon solution.

4.2.2. Inspections and price quotation

To perform the quotation of the project, Evogy was in contact in a first phase with the technical director of the Humanitas group. Thanks to a strong collaboration with the director of the group, the more suitable building was detected as pilot case, i.e., the polyclinic detached from hospital in the *Fiordaliso shopping center* (as the health industry tendency is to place building in people transit areas) situated in Rozzano, a small town near Milan. Its opening time depends on the medical service provided. All general examinations can be booked from Monday to Friday from 8.00 a.m. to 7.00 p.m. but not blood tests, which can be taken from Monday to Saturday from 7.30 a.m. to 12.00 p.m. (this defines the theoretical utilisation time of the system).

The health-centre is composed of two thousand square meters, divided into two floors: while the reception and blood tests rooms are at the ground floor, the outpatient facilities for X-rays and other examinations are at the first floor.

In a second phase, both the energy manager and the maintenance manager of the specific building were involved in the project. Two inspections were conducted (lasting 1 h each) to define the plant engineering as-is (verifying the type of lighting, heating and cooling systems and how they were connected to the electricity switchboards (since no gas systems was present). The plant census was conducted to assess the heating, cooling and air circulation in the building. Then, the electric system was studied to understand how it was linked to the electric control panel.

Alternatively, a checklist could have been filled by the customer to enable Evogy to prepare the quotation. In it the customer is supposed to provide all the needed information about the type of building, of industry and of machineries, the presence of inverters and of co-generation systems, and also makes available the diagram of the low voltage electrical distribution, the machinery datasheet and the yearly consumption history energy diagnosis (for electricity and gas). In this phase, the main issue has been, and usually actually is, the maintainer reluctance to share his knowledge of the system, since from his perspective the Simon system represents a threat for his work.

4.2.3. Hardware procurement, system installation and commissioning

After this, the concept prototype was drawn up. Figures 3 and 4 represent the virtualization of the physical plant, respectively of ground and first floors.

In order to analyze the energy consumption of the buildings, while Evogy S.r.l. placed sensors to measure the internal temperature, humidity, lux and CO_2 level, external data were also provided by the connected weather station. Furthermore, having the health centre many small rooms, sensors were located only in common areas, such as the waiting room and corridor. Nevertheless, measurements obtained were significant because the highest values, especially in terms of carbon dioxide, due to the presence of more people, are reached in these places.

As Figure 3 shows, near the centre of the meeting room, there are the probe for CO_2 and temperature measurement (C3) and the CO_2 repeater (R), useful to amplify the signal. The THL probe (Temperature, Humidity, Lux; T4) is located at the corner on the upper-right hand side of the chamber. Then, having two temperature values, Simon gives as output also the arithmetic mean. Finally, outside the building, there is the external THL probe (E).

On the first floor (Figure 4), being the total surface nearly the double, not only more sensors have been installed but also the gateway (G) and the display of the three power meters: general (P1), polyvalent pump (P2) and technical room (P3). Next, there are three THL probes (T1, T2 and T3). Also, in this case, having different values of carbon dioxide and temperature, Simon displays the means of them. Moreover, the plant shows also the presence of two probes for CO_2 and temperature measurements (C1 and C2) and two CO_2 repeaters (R) but, due to logistic problems, they have not been installed. Overall, all sensors and their functions are summed up in Table 4.

Wrapping up, three different power meters were inserted, splitting the whole system in three parts:

1. The general power meter on the general electric system (considering lightning and small utilities),
2. The polyvalent power meter on the heat pump (for heating and cooling),
3. The air handling unit (AHU) power meter on the AHU.

Through the energetic audit the yearly consumption (resulting to be 37 k€/year) and the percentage of consumption of each part (as respectively 12%, 65% and 23%) were defined.

In addition, in the proof of concept four sensors were considered in the building: one per floor for CO_2 and one per floor for combined temperature and humidity. Also the area and height where these sensors had to be placed to give reactive values were defined (since the variables considered are very affected by the height where the sensor is placed). Few sensors were installed since it was a first proof of concept to be expanded in the future developments wirelessly (through a narrow band ZigBee communication protocol).

Moreover, the building, built in the 2015, had already a first level of intelligence (BMS from an external provider) governing the machines (for heating and cooling) and coordinating them locally to give the desired comfort. The BMS, linked to the air-handling unit and to the heat pump, had the function of Supervisory Control And Data Acquisition (SCADA) of the system, not driven at energy saving but only at the effective operation of the machines.

Figure 3: Virtualization of the ground floor (Legend: T=Temperature, humidity and lux measurement; C=CO_2 and temperature measurement; R=CO_2 repeater; E temperature, humidity and lux measurement outside; G=Gateway; P=Power meter)

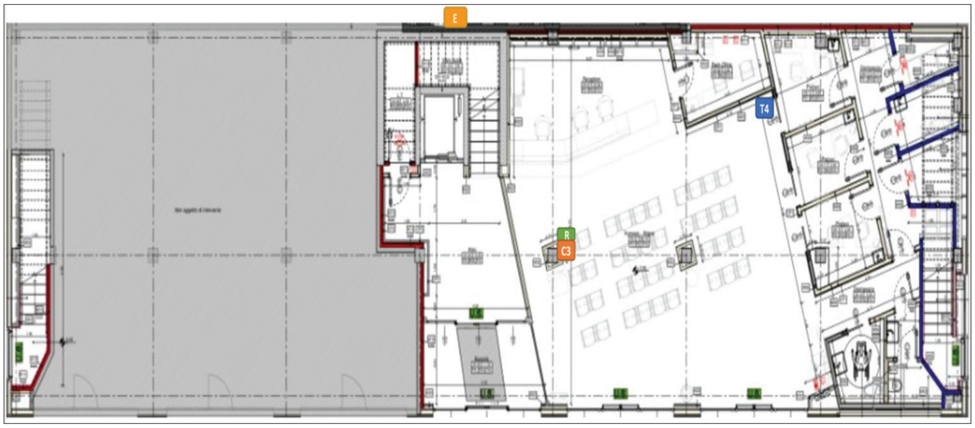


Figure 4: Virtualization of the first floor (Legend: T=Temperature, Humidity and Lux measurement; C=CO_2 and Temperature measurement; R=CO_2 repeater; E Temperature, Humidity and Lux measurement outside; G=Gateway; P=Power meter)

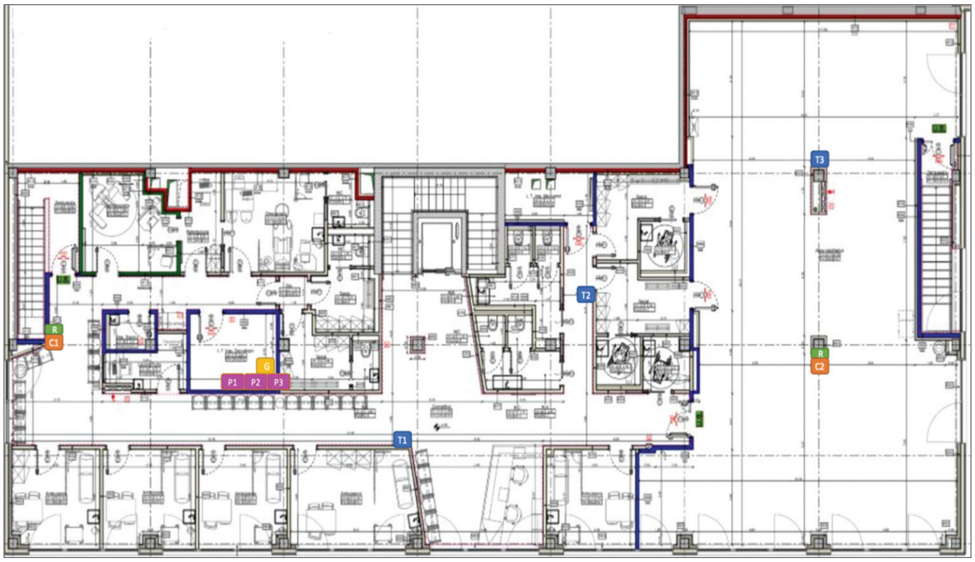


Table 4: Sensors summary

Probe	Location	Functions
C1	Corridor 1st floor (not installed due to logistic problem)	CO_2 and temperature measurement
C2	Lobby 1st floor (not installed due to logistic problem)	
C3	Meeting room ground floor	
T1	Corridor 1st floor	Temperature, humidity and lux measurement
T2	Changing rooms 1° floor	
T3	Lobby 1° floor	
T4	Corner meeting room, ground floor	
R	Lobby 1° floor (not installed due to logistic problem)	CO_2 repeater
R	Corridor 1° floor (not installed due to logistic problem)	
R	Meeting room ground floor	
E	Outside	Temperature, humidity and lux measurement
P1	Technical room 1° floor	General power meter
P2		Polyvalent power meter
P3		Air handling unit power meter
G	Technical room 1° floor	Gateway

4.3. The Application Case: Monitoring and Control Phases

4.3.1. Monitoring phase

After having installed the hardware needed, the entire system has been monitored for three months. During this period, the customer can actually realize his consumptions remotely and Evogy could assess the data gathered on the system (Figure 5).

In particular, Figure 6 (left) shows also the power always absorbed by the AHU and, as it should be, it follows the energy pattern (Figure 6 [right]). Power usage fluctuates continuously during working days between 3.3 kW and 5.3 kW. However, while peaks are only reached during daytime hours, troughs are present not only at nights but also during mornings, afternoons and Sundays.

Furthermore, Figure 6 (right) illustrates the weekly electrical energy consumption of the AHU. Overall, it is immediately apparent that while the utilization from Monday to Saturday is almost stable, it decreases on Sunday. Consequently, the consumption in working time is around 90 kWh. However, being the healthcare open only half day on Saturday, the energy usage is

Figure 5: Weekly active power (left) and energy (right) absorbed by the AHU before the action

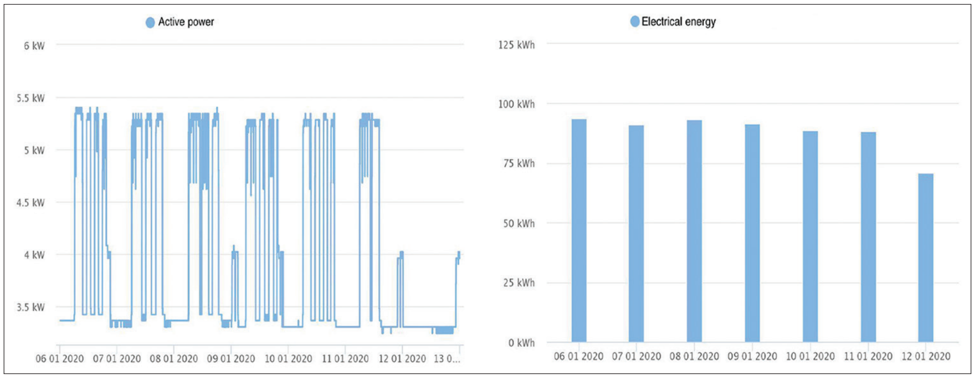
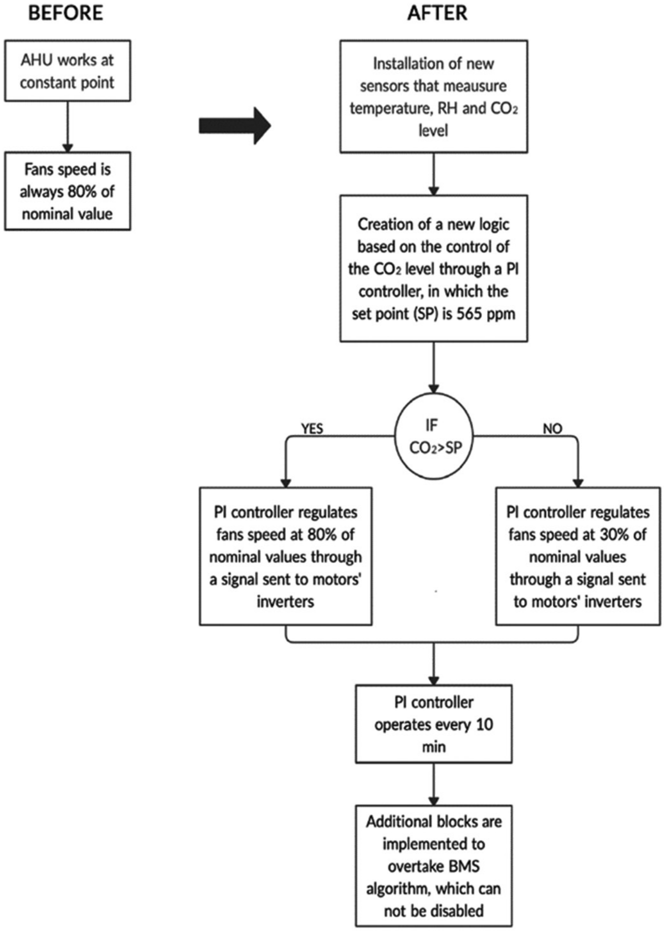


Figure 6: Flowchart AHU functioning before and after the action (Legend: RH=Relative Humidity; SP=Set Point; PI=Proportional Integral)



still comparable with the previous value; in fact, there is a drop of only 2 kWh. Finally, by consuming around 70 kWh, the Sunday decline is more marked but, not too steep.

It has to be said that already in this phase some anomalies could be detected and improvements enacted. Indeed, in the specific case of Humanitas, the customer had a system with inverter and the maintenance technician had set the system with fixed point (blocking the inverter and thus limiting the system dynamicity).

In the meanwhile, bad practices were recognized also on the air-handling unit: Simon's adoption enabled a cut in terms of energy consumption by monitoring CO_2. Before Simon's adoption, external CO_2 was monitored and thus the system wasn't able to provide a suitable air exchange. In the new design of the system, CO_2 was monitored internally, as it should normally be. Therefore, Simon is able to improve the overall management of the system and make the maintainers' work more effective and efficient, providing them continuous information on the functioning of the system (thanks to the monitoring through the sensors installed) and correcting and suggesting activities to be implemented daily.

Due to the issues raised in the previous paragraph, after monitoring the system for three months, it was estimated a saving of 8% ÷ 12% on the AHU and the same value for the heat pump. Based on them, the customer was convinced on the implementation of the control functionalities.

4.3.2. Control phase

Implementing Simon's control functionalities, in the first three months a saving of 45% on the AHU and of 15% for the heat pump unit was registered. Moreover, during this time lapse, two months of COVID19 occurred, shifting the objective driver from energy savings (with a standard level of 900 parts per million of CO_2) to volumes of air changed (acting on pressure and de-pressure). Indeed, the COVID-19 pandemic in Italy had its initial epidemic manifestations on January 31, 2020 and is currently circulating everywhere around the world. Due to its high mortality and ease of transmission, the AICARR (*Associazione Italiana Condizionamento dell'Aria, Riscaldamento e Refrigerazione*) has published the changings on the HVAC system in workplace (AICARR, 2020). It compelled Evogy to implement the following modifications on the system:

- Increased airflow (by changing the number of fan rotations, so the power supply frequency controlled by two inverters);
- Forcing dampers in external air only (for the sole purpose of increasing the external airflow rate, the recirculation damper must be closed, and the inlet one must be opened at the same time, but as there is no recirculation in the AHU, this point has not caused any variation);
- Deactivation or by-pass of the heat recovery system (being a cross-flow energy retriever, the risk of contamination is unlikely; so, also in this case, it has not produced any change);

- Maintaining the set-point of the relative humidity above 40% (useful because low RH values tend to make the mucous membranes dry, facilitating the entry of the virus. In this case, humidity was already above the minimum value).
- Continuous operation of the external air supply (this intervention consists of letting the AHU work continuously to guarantee the presence of fresh air, even during non-occupancy hours of the building).

These five points are in contradictions with the CO_2 algorithm but, to ensure safety inside the healthcare, they had to be implemented, always trying to limit the amount of energy spent.

During the control phase, Simon acted in a predictive way, considering the thermal inertia of the system. Indeed, having studied and modelled the building, the heat pump knows its behaviour based on the external temperature (weather forecast), also enabling sometimes a free cooling (especially in the middle seasons when the external temperature is the same as the internal one).

After having analysed in detail the absorption of the main components of the plant, it is clear how more dynamic logics of control can be implemented. Their development depends on the following constraints:

- Stopping the polyvalent pump would also mean stopping the AHU, otherwise the air supplied inside the building would be either too cold (winter) or too hot (summer);
- In case of extremely low external temperatures (below 3°C), the polyvalent pump must continue running, otherwise the fluid inside pipes would risk freezing and blocking the normal operation of the system;
- Domestic hot water has very strict temperature limitations: to avoid the presence of *Legionella* inside the tank, it must never fall below 45-55°C;
- Since the system under analysis is a healthcare building, there are rooms (e.g. those in which there are medicines), which must always be within a set temperature range: 20-24°C. Consequently, a complete stop of the system is not allowed during nights and weekends. The only option is improving the actual functioning by modifying parameters and set-points without changing environmental conditions and comfort.

Furthermore, since the BMS provider manages the entire plant through its system (which can not be deactivated), it will always have priority over the logic set by Evogy S.r.l. through Simon, which works on another level. Consequently, in the case of the AHU, in order to bypass the BMS algorithm, in addition to the Proportional Integral (PI) controller, another check has been added that avoids abrupt and unwanted variations of the air rate. Indeed, the control of the AHU is based on a PI controller, which operates according to the amount of CO_2 in the environment. It is a very efficient solution in places characterised by a highly changeable occupancy. The success of CO_2-based Demand Controlled Ventilation (DCV) succeeds in the direct verifying of indoor air quality level and the following evaluation of necessary air changes. Thus, this component moves from a programmed operation to one dependent on the level of carbon dioxide in the building. Since it is a healthcare, which only works on appointments, a PI and (not a Proportional-Integral-Derivative (PID) control system) has been chosen because a sudden and massive presence of patients is not expected. Consequently, it can be inferred that the dynamic of the system is slow. In fact, PI controllers are used when a low-speed error is required together with a good speed response to stress variations. Therefore, they are mainly utilised in systems where load variations occur slowly.

Overall, a summary of the states before and after the action are represented in Figure 6.

Finally, the economic benefits should be evaluated. Being “Il Fiordaliso” connected to the low-voltage grid (380 V), energy losses are equal to 10.4% of the total energy consumed (ARERA, 2020). Moreover, the available power or, in other words the maximum withdrawable potential above which the supply could be interrupted, is equal to 150 kW. The power shared is one of the non-negotiable items on the bill and it is paid differently among users. Domestic and non-domestic consumers up to 30 kW pay the monthly fee on all contractually committed power, even if not used. Since 2008, on the other hand, industrial consumers or users with a power larger than 30 kW (healthcare’s case) pay the monthly fee only on the peak power absorbed in the month (as measured by the meter). On the other hand, the energy cost varies at different times of the day and on different days of the week (so, it is divided into time bands, and different prices are also applied to the final customer depending on the time of use). In the case under analysis, the division is as follows:

- Peak hours: from 8 a.m. to 8 p.m., from Monday to Friday;
- Out peak hours: from 8 p.m. to 8 a.m., from Monday to Friday and Saturday, Sunday and public holidays.

Only voices linked to energy are taken into account, while the ones related to power and fixed consumptions are neglected. The reason is that, through the actions made, the reduction of the peak power may at most be to 3-4 kW and, consequently, in the period comparison, the cut will be equal to a few euro cents. The same happens for fixed costs, which do not modify savings between the two periods. Hence, the economic benefit is evaluated by multiplying the energy consumed by its cost, both on each timeframe.

Figure 7 describes the comparison between the energy costs, divided by time bands, before and after the action on the AHU. As can be seen, before the action of Simon the difference between peak and out-peak was around 20 €/week (due to the high baseline absorptions [Figure 7 left]), while after it has been reduced to nearly zero. Furthermore, the peak consumption is more than halved, moving from 43 €/week to 20 €/week but, the most significant decrease is achieved on the out-peak band, in which the cost is three times less than before (from 60 €/week to 20 €/week). As a result, the two bands, after the intervention, have a comparable price.

Moreover, Figure 8 illustrates the total economic benefits obtained on the AHU. It is immediately apparent how the weekly energy price has experienced a sudden fall, moving to about 100 €/week to around 40 €/week. Finally, by always analysing its trend in

2019, the assumption of a similar decrease for the entire year can be made and potential savings can be computed.

As illustrated in Figure 9, the old functioning (blue line) of the AHU has been overtaken by one which operates through the monitoring of the CO_2 level (red line). In that way, more efficient usage of the energy has been reached, obtaining enormous savings in terms of money, energy and CO_2 equivalent not discharged in the environment, obtained through different types of algorithms. Consequently, the use of both IoT platform and CO_2 sensors are confirmed as a logical approach at this time: in fact, DCV technology has shown its easy utility even in historical raisings and its important support to HVAC system efficiency optimization (Schibuola et al., 2018).

However, due to COVID-19 restrictions, this logic has been modified again (green line) even if savings are still obtained in comparison with the oldest configuration, demonstrating the initial mismanagement (Table 5).

Figure 7: Electrical energy cost of the AHU divided by time bands before and after the action

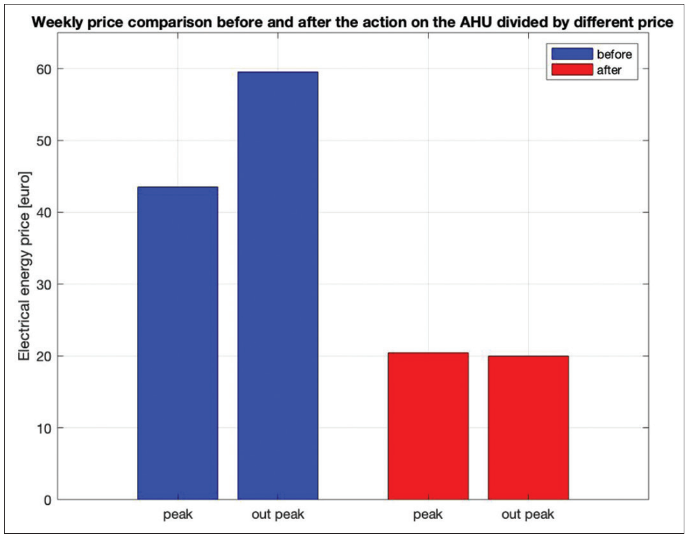
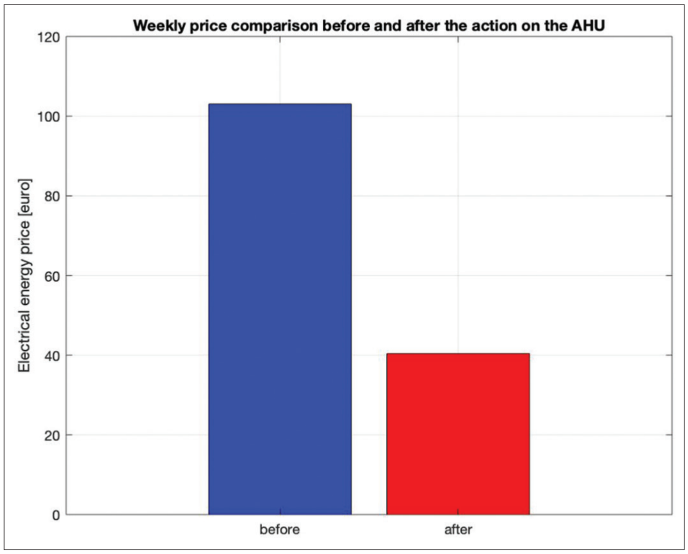


Figure 8: Electrical energy AHU before and after the action



Another significant point to notify deals with the spurious peaks in the afternoon on the AHU's active power trend (Figure 10). They are not due to an abrupt change of functioning but to other factors (as recirculating pumps, production of domestic hot water) measured by "Active Power". Indeed, temperature and humidity have not changed their trends before and after the action on the AHU, continuing to respect standards values. On the other hand, benefits of the new functioning of the polyvalent pump, being seasonal, have not been estimated. Being the related algorithm much lesser impacting than the one on the AHU, savings are much less significant (no more than 10%) and not comparable.

5. DISCUSSION AND MANAGERIAL IMPLICATIONS

Depending on the customer needs and requests, Simon can provide different set of services and, from a PSS perspective, can be either

Figure 9: Airflow rate in all the three configurations (before action, after action,COVID-19)

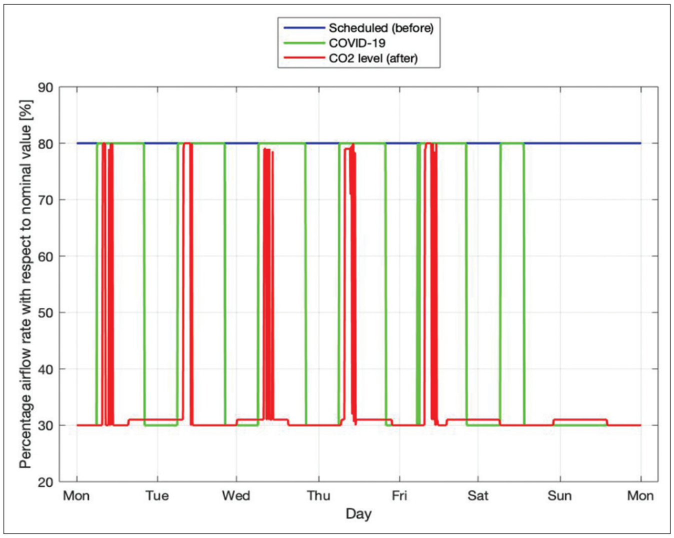


Figure 10: Weekly active power absorbed by the AHU before and after the action

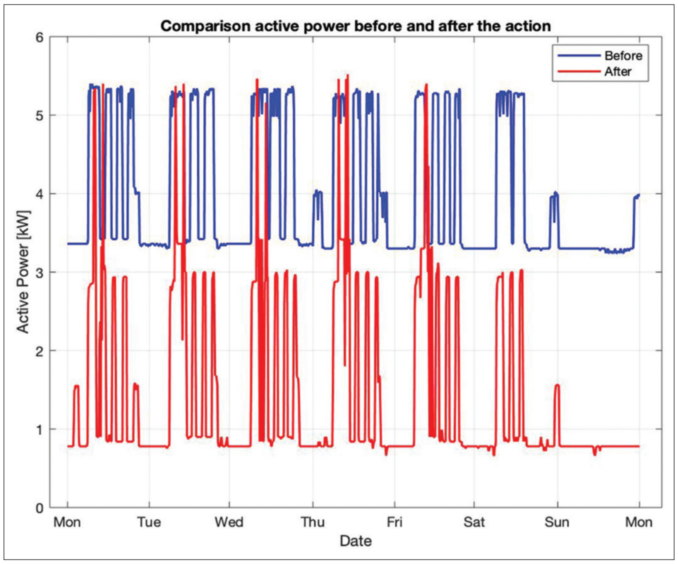


Table 5: Summary data obtained on the AHU in all configurations

	Yearly values			
	Electrical energy [kWh]	Primary energy [tep]	CO_2 discharged [ton]	Energy cost [€]
Scheduled (before the action)	29520	13.36	12.81	4948
CO_2 algorithm (after the action)	11568	5.23	5.02	1939
COVID-19 constraints	17376	7.86	7.54	2942

a product-based PSS or a functional-based pay-per-result solution, providing its customer with complete *in-situ* tailored services.

Indeed, as shown in Table 2, five services are categorized as product-oriented, three can be provided either as product- or result-oriented, and the last two as result-oriented. The shift from product- to result-oriented services is driven by a rise of smart capabilities (from their lack, through monitoring, up to autonomy), depending by an always higher employment of digital technologies used to delivery these services, and bringing higher benefits to the three main stakeholder involved (customer, provider and TSO).

In detail, looking at product-oriented services, the first two services in Table 2 (consultancy on the modelling and design of the building infrastructure; installation/start-up and commissioning of the required technologies) can be considered pure product-oriented. They require a minimum use of digital technologies, do not enable any smart capability and bring few benefits only to the customer and provider of the PSS.

Other three services (Plant geolocation; Diagnosis and reporting: dashboard and graphic features; Help desk for product, process and business) can be included in the product-oriented context and are characterized by monitoring smart capabilities. In this case, it can be noticed a first involvement of AI and an indirect benefit also for the TSO.

There are three services, mainly playing a control smart function, that are product-oriented but can converge to the result-oriented dimension (updates/upgrades of HW and SW; remote control from centralized platform; alarm management and sending of commands in single and aggregate formats). Indeed, all of these services can either be delivered as simple add-on services of the physical product or can also contribute to the achievement of the results targeted on the contract of the result-oriented PSS. Their delivery requires a strong use of AI and directly activate the TSO's involvement.

Finally, the last two services in Table 2 are pure result-oriented (Advanced data analytics and model construction and autonomous remote control of the entire building; Demand Response mode for balanced grid congestion and electricity network services). They require a full adoption of the three digital technologies (IoT, CPS and AI) and provide benefits to all the stakeholders of the PSS solution in a dynamic way.

Indeed, through CPS- and AI-based approach, Simon not only monitors the consumption but also actuates the equipment. This can be possible thanks to a simulation and an equipment "cyberization," always considering the customers conditions constraints (e.g. comfort for people in the building). Thanks to this, a result-oriented PSS can be provided, avoiding for its provider the need of ordinary maintenance on equipment and opening the way to a digital-based predictive maintenance on the real system. Its adoption will bring the PSS provider to increase its competitiveness on the national and international market and conquer new customers. Moreover, the company's competence and value will increase on the market due to the increasing competitiveness of the EMS (the Simon platform). This is also translated on one side, for the PSS provider, in a better maintenance (preventive with less machine downtime and reduced costs), a reduced environmental impact and an easier achievement of target consumption results of the result-oriented PSS contracts. On the other side, for the customer, it turns out in a reduction of energy consumption, saving of money and an enhanced customer comfort. Finally, from the TSO perspective, the Demand Response mode gives the opportunity to detect and map existing plants and to manage their power and energy in an efficient and effective dynamic way through the creation of VPP of plants.

Going in the detail of the Humanitas hospital case, costs and benefits deserve to be discussed. Simon costs are divided in CAPEX per project setup (hardware, inspections and commissioning) and in OPEX, consisting in an annual fee for data management (in "pay as you go" way) and optimization algorithms for each asset/equipment involved. The pay-back period is expected to be in 24 months and discounted pay-back period shows similar results. Specifically, based on the savings generated, the system pays back for itself in this time by indirectly obtaining other benefits:

- Humanitas increased its bargaining power, reducing the fee to the BMS provider to 70%,
- The well-being of users has being increased, enabling remote set-up and control,
- Maintenance turned to be predictive (no more scheduled and preventive), with a saving of 10% of the maintenance fee, since the alerts arrive on the basis of the monitored operations.

Moreover, thanks to the adoption of the Simon digitized and servitized solution, several long-run opportunities for the customer have to be raised. In fact, Humanitas pays a high annual service fee to the BMS provider (being locked-in by the purchasing and installation of the BMS needing a maintenance contract). The adoption of Simon could play an important role in recovering additional savings and sustain those costs. In the long run, Humanitas could also knock off the BMS maintenance service contract with the BMS provider, leaving to Evogy its management. In case of its break, Evogy can also substitute the BMS hardware from the external provider with its own control board, translating BMS functions on edge (hence no more connected to the external PLC field controller). In this way, it is possible to switch from a vertical field BMS, provided by a single brand, to a multi-protocol system that takes the field data and throws them on the cloud.

Indeed, the possibility to connect whatever device is enabled by the IoT control board, avoiding to the customer to be locked-in a specific brand. Indeed, SIMON is able to work simultaneously with systems using different protocols: i.e. sensors using ZigBee, power meters by means of Modbus and also the BMS adopting Bacnet. In this way, Evogy's control board does not gather anything locally (shifting all the data on the cloud), is able to predictively interface with external data (such as weather forecasts) in real time and can set multiple performance indicators to create intelligent operations.

The provision of AI-based services brings several benefits. First of all, it allows Evogy (intended as a PSS provider) to differentiate themselves from their competitors, offering a valuable platform/EMS that enriches in a significant way the features of IoT-based services. Indeed, through its adoption, Evogy can provide services based on an algorithm that enables to take the best possible decisions and to consider different drivers. The algorithm can be of two types:

1. forecast-based algorithm: aiming at an optimal cost/consumption point through the definition of several drivers. In this case, it is important to choose the drivers (temperature, humidity or CO_2 level in the air) also related to the compliance of the COVID-19's descriptive rules. Indeed, while IoT-based services can merely aim at no air recirculation and no free-cooling, through the forecast-based algorithm different constraints can be set to maintain almost the same consumption/cost objective.
2. Machine learning (ML) algorithm: in the face of a slight loosening of the service level agreement (SLA) of energy efficiency, the ML algorithm can bring even major benefits. Starting from the insights of the forecast, this kind of algorithm trains itself through the historical data gathered from the building and the boundary conditions (e.g. weather forecast). In this way, the ML algorithm can be considered a referring meta-model to be instantiated to each building, progressively tailoring its behaviour on the system analysed along the time. Compared to the manufacturing industry, it can be adopted in an easier way in the tertiary market since here the requested customized part is lower. A referring algorithm can be developed in a first pilot case (Humanitas building) and once validated on another system (setting the input drivers and analysing its characteristics) it can be used with a good scalability and replicability.

The use of ML algorithms concur to allow Evogy to better the energy demand response. Indeed, not only it is important to be able to satisfy the SLA required by the customer but also to be able to either spend in a more efficient way on the energy market or aggregate the saved energy and offer it on the ancillary services market, such as "balancing market", (through national electricity grid, TSO or the forthcoming energy communities) can trigger very important benefits.

Nevertheless, a model based AI hybrid approach for demand response requires flexible consumers that need to sign a release in case of energy surplus and a declaration of availability to share this amount in the VPPs (to which they are already technologically enabled through the Simon platform) (Figure 11). Through this mechanism, two main types of actions can be implemented:

- Energy pick shaving: on the single customers' point of delivery (POD) to avoid power picks affecting the monthly costs.
- Energy load shifting: it is possible when the energy price is not fixed and drives the purchase of energy depending on the value of the national unique price (PUN), variable with the renewable energy share.

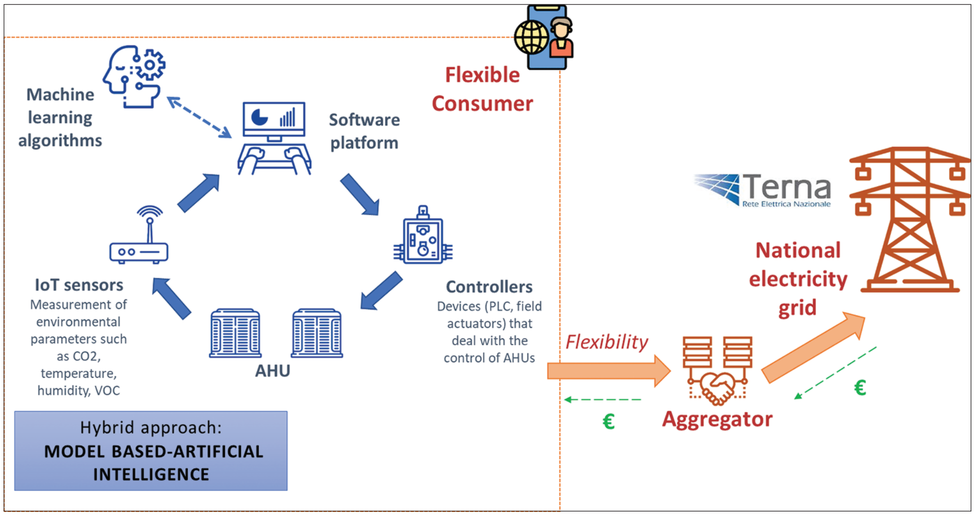
In addition, Terna has the aim to balance energy supply and demand, intervening *ex post* by buying or selling capacity (to subtract or release energy) at a profitable price. Balancing Service Providers (BSPs) have the scope of bringing together a certain number of distributed resources and jointly offering the related services to the network operator. Indeed, Terna's counterparty for the supply of dispatching resources is the BSP, who manages the participation to energy dispatching activities also of smaller entities called virtually aggregated units (UVA). Evogy, playing the role of technological enabler between the BSPs and the VPPs, manages the aggregated energy and suggests to the BSPs at what price a certain amount of energy has to be supplied.

Terna has imposed 1MW as the minimum energy threshold to be aggregated in VPPs (without constraints of users homogeneity) and to be offered on the energy market. The tough activity for Evogy is to technically manage the single users of the VPPs (several customers as Humanitas can be gathered together to satisfy the needed critical mass), maximising customers' auto-consumption but also the saved energy made available to the energy communities. Moreover, Evogy has to conduct forecasts to take decisions and estimate the flexibility of the single users in getting on and off in power based on the predictions of the algorithms.

However, being Humanitas the first customer using Simon, new users are needed to participate to the energy community to be able to reach the threshold set by Terna at national level (that has been decided externally and does not depend on the PSS provider). In last year, Evogy worked on several other cases, pertaining to different business contexts, (e.g., in the mass retailing and in the production and warehousing of pharmaceutical products).

Finally, to understand the difficulty in arranging and putting together such a complex solution, it is also important to highlight the organizational complexity of Evogy's ecosystem. Indeed, Evogy needs to deploy heterogeneous competencies, bridging the twofold energy and digital domain. For this reason, in the development of such a solution, Evogy needed a supporting network of companies with complementary competencies. This is the case of the divisions dedicated to coding and data science. Being a start-up, Evogy cannot directly enlarge these divisions with new employees proportionally to the increase of the projects managed that however can be managed empowering the platform, the algorithms and the AI. Thus, they decided to have, keep and maintain inside them the solution architect, in charge of the design of the solution (in other words the father of Simon), to fully control the system and know its limits and strengths. This actor can be considered a knowledge broker in the Evogy's ecosystem (i.e., a

Figure 11: A model based AI hybrid approach for demand response: flexible consumers composing virtual power plants



set of companies sometimes in strict partnership and most of the times indirectly controlled [owning part of the shares of them]). He defines the requirements and coordinates all the activities conducted in the Evogy's ecosystem. This is the case of Runelab who coded the platform. In this way, Evogy can outsource important and heavy activities, entrusting them to companies strictly related and with common vision and business. In addition, in this way Evogy from one side avoids to fall in risks related to the software designers market, typically difficult to manage and not stable, due to their high rotation rate in different companies. From the other, software designers working for Evogy are not completely focused on the Simon solution, enabling in this way a sort of opportunity of cross-fertilization from different domains. The same dynamic has been employed with data scientists. Evogy has an internal person who develops technical specifications and manages internal projects. Data scientists' work is then needed for developing algorithms in multiple domains (e.g. food machinery, weather algorithm, etc), requiring a lot of effort.

It can be said that Evogy keeps internally the pillars allowing to directly manage this interaction with loyal external and shared companies. This ecosystem fosters the exchange of knowledge, experience, skills and assets among the different stakeholders involved (Vlados et al., 2021). This form of ecosystem can direct towards the sustainable hand model where it is evident how new social models are required (D'adamo et al., 2022). The energy sector plays a key role towards sustainability goals and the residential sector is called upon to contribute. The literature has placed attention on the contributions that digital technologies can make (Karttunen et al., 2021; Ullah et al., 2021) and the future direction of research is to combine these two strategic aspects: sustainability and digitization.

6. CONCLUSIONS

Sustainability and digitization are two key-topics of the Next Generation EU and this work proposes the impact of digital technologies in the EM. The research method adopted was designed with the intention of building the model consistently to the EM in smart building industry, adopting an interpretative, interactive and system development based research approach conducted in a DIH environment to boost its digital potentialities.

Several results have been presented to permit a replicability comparing performances. From a theoretical point of view, several aspect have been presented. First, the Simon model has been proposed, declining the main technologies involved in it to implement a digital EMS. Second, its structure has been shown, highlighting its orientation to manage systems in multi-site configuration, being characterized by a hierarchical division of the related knowledge into levels. Finally, the functionalities of the model and the services enabled by its use have been discussed.

From a practical perspective, benefits provided by Simon to its stakeholders (mainly customers, provider, TSO) can be summarized in four categories: cost reduction, reduced environmental impact, enhanced customer's comfort and improvement of maintenance (that becomes predictive and brings to a reduction of machines downtime and maintenance costs). In addition, the demand response mode can be activated to balance the electricity grid and create electricity network services through dynamic VPPs of plants. Indeed, this research wants to demonstrate that digital technologies enable and foster the product-service solution provision (especially result-oriented ones), leading to a set of benefits for all the stakeholders involved.

Results, referred to the pilot application case, are impressive. In fact, different types of benefits are identified: environmental (pollution reduction), economic (cost reduction) and social (users comfort). Furthermore, it must be said that the Simon model has huge potentialities and can be expanded and used in different types of buildings and industries, creating new business opportunities. Some important considerations in this wider application to new contexts should be done about the current and future skills required and level of human-machine interaction. The application of SIMON can be replicated mainly in three contexts:

(i) residential area in which energy represents a cost and there is also an increasing pressure on sustainability,

(ii) tertiary sector which can gain the benefit of this solution and optimize also the building management thanks to a CPS approach,
(iii) companies (SMEs and large enterprises) which could apply the same infrastructure to improve also the employee satisfaction and the work environment and comfort.

Finally, the COVID-19 pandemic the world is facing has led to drastic modifications in ventilation and climatization rules. Once defeated the pandemic, the key to maximize savings could be to implement either a predictive method for ventilation scheduling or a building behaviour modelling through the use of self-learning algorithms that, based on the weather forecast, proposes the setting logic of the systems and environmental comfort.

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