Energy efficiency in Long Term Care facilities: results from the retrofit of heating control systems

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Abstract. The paper presents the efficiency project that Enerbrain collaborated on in 2024 to upgrade the heating control systems of nine Long Term Care facilities in France. The retrofit consisted of an IoT-based solution integrating local controllers with a cloud-based control algorithm, aiming to implement BACS class B control functions within legacy heating systems. The results of this study demonstrate that these retrofit actions led to an average 29% reduction in heating energy use intensity and provide interesting insights on how to perform energy savings assessments taking into account the actual complexity of facility management activities in tertiary buildings.

1 Introduction

It is nowadays well acknowledged that energy efficiency represents one of the most effective ways for reconciling economic progress, emission reduction, and sustain-ability to meet the ambitious European goal of achieving climate neutrality by 2050, as mandated by the European Climate Law [1], and that the building sector - which accounts for approximately 40% of EU energy consumption - plays a key role to reach it.

Several strategies can be deployed to achieve significant energy reductions in buildings, ranging from the enhancement of building envelope thermal resistance to the integration of renewable resources and thermal storage. This paper specifically examines the impact of Building Automation and Control Systems (BACS). The strategic importance of BACS has been reinforced by the Energy Performance of Buildings Directive [2] within the "Fit for 55" framework, which targets a 55% reduction in greenhouse gas emissions with respect to 1990 levels by 2030 as a critical milestone toward 2050 neutrality.

Narrowing the focus to the existing building stock, tertiary buildings are responsible for 13,5% of the total final energy consumption in Europe, with 11,1% of that share attributed to healthcare and social assistance facilities, including hospitals and residential care [3]. Among them, Long Term Care (LTC) facilities are gaining their momentum, considering the socio-demographic trends that Europe has witnessed in recent years, which combine the gradual rise in average age with a progressive reduction in the ability of family units to assist the

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elderly. The efficient management of these buildings represents both a commercial necessity and a prime opportunity to demonstrate the efficacy of advanced energy efficiency measures.

Since residents are often over 80 years old, LTC facilities must maintain stringent indoor environmental quality standards 24/7. Consequently, energy intensity often exceeds 200 kWh/m² in 70% of European cases [4]. In these contexts, heating constitutes the primary energy cost, followed by light-ing and Domestic Hot Water (DHW). Therefore, retrofitting solutions that optimise system management via BACS without compromising occupant comfort are of strategic importance.

In France, the regulatory landscape actively promotes such interventions: the *Décret Tertiaire* [5] mandates a minimum 40% reduction in energy consumption for tertiary buildings by 2030, while the *Décret* BACS [6] requires the implementation of automation systems by 2027. Furthermore, the *Certificats d'Économies d'Énergie* (CEE) mechanism, specifically through the BAT-TH-116 scheme [7], provides the necessary financial framework. Within this policy environment, French nursing homes are ideal candidates for upgrading Building Management Systems (BMS).

This is the context for the efficiency project that the authors of this paper collaborated on in 2024 to upgrade the heating control systems of 9 French Long Term Care facilities. The project put together the interests of a leading European private healthcare and eldercare operator, who owns/manages the facilities (in the followings "the Customer") , the expertise of one of the main French services companies specialised in engineering, construction and maintenance for thermal and electrical systems, who installed the new control systems and HVAC components, and the technical solution developed by Enerbrain, which optimised the management of the main Heating and DHW components by exploiting IoT technologies combined with a cloud-based intelligent algorithm.

The following paragraphs describe in detail the retrofit intervention carried out, aimed at upgrading the buildings' BACS class to A or B (see UNI EN ISO 52120-1 classification [8]), and showcase the energy savings achieved following the implementation, completed by December 2024.

2 Case study

The case study under analysis, consisting of 9 Long Term Care Facilities across France, represents the pilot phase of a large-scale energy efficiency program targeting a vast healthcare portfolio of over 200 French facilities managed by the Customer. To validate the efficacy of the proposed Building Automation and Control (BAC) strategies before a potential nationwide roll-out, the 9 buildings were selected as experimental case studies. The selection methodology, developed by the Customer in collaboration with Enerbrain, prioritised sites based on two critical technical criteria: (i) the presence of high-inertia hydronic heating systems and (ii) a high baseline Energy Use Intensity (EUI), thereby ensuring the statistical significance of potential energy savings and a viable Return on Investment (ROI). To account for environmental variables, these pilot sites (anonymised in the followings of the paper as "RSA_FR_XX") are distributed across diverse French climatic zones. As summarised in Table 1, the facilities are characterised by substantial heated floor areas, ranging from 4.000 to 6.000 m², with an occupancy capacity from 60 to 130 beds.

From a systems engineering perspective, the mechanical plant topology in 7 of the 9 facilities features a centralised thermal plant with two condensing gas-fired boilers in a cascade configuration, with Domestic Hot Water production typically relying on a buffer storage system equipped with recirculation loops to minimise distribution losses and maintain thermal hygiene. Technical variations within the sample include one facility integrated into a district heating network (RSA_FR9) and another featuring a non-standard DHW storage configuration (RSA_FR6). In all sites, the distribution architecture comprises hydronic networks with both direct and mixing circuits, managed by single or twin pumping groups with constant or variable speed control. Space heating is typically delivered through a hybrid terminal unit strategy: high-inertia radiators are utilised for continuous climate control in circulation areas and private rooms, while more dynamic common spaces - such as lounges, dining facilities, and reading zones - are served by a combination of radiators and fan coil units to accommodate transient thermal loads.

The pre-retrofit energetic characterisation of the pilot cohort reveals a mean thermal Energy Use Intensity of approximately 150 kWh/m^2/y. A functional assessment conducted according to the ISO 52120-1 standard [8] categorised the pre-retrofit BACS infrastructure as Class D ("Non-energy efficient"). This classification underscores a systemic absence of demand-side management and optimised control logic, establishing these facilities as a robust benchmark for evaluating the performance delta achievable through advanced automation and cloud-based optimisation algorithms.

Table 1. Details of the hydronic systems in the case studies.

Building code	**Area [m^2]**	**Beds**	**Energy Use Intensity [kWh/m^2/y]**	**Heat generation**	**Distribution: N° of circuits**	**Emission**	**DHW**
RSA_FR1	4.955	101	104	2 gas boilers	3	radiators, AHU	storage, recirculation
RSA_FR2	5.807	60	165	2 gas boilers	9	radiators, fan coils	storage, recirculation
RSA_FR3	4.100	108	164	2 gas boilers	5	radiators, fan coils	storage, recirculation
RSA_FR4	6.000	115	131	2 gas boilers	8	radiators, fan coils	2 storage, recirculation
RSA_FR5	4.500	89	194	2 gas boilers	2	fan coils, AHU	2 storage, recirculation
RSA_FR6	4.728	100	174	2 gas boilers	4	radiators, fan coils, AHU	recirculation
RSA_FR7	4.500	70	111	2 gas boilers	2	Radiators, AHU	storage, recirculation
RSA_FR8	4.700	102	179	2 gas boilers	4	radiators	storage, recirculation
RSA_FR9	5.787	127	132	District heating	3	radiators, AHU	storage, recirculation
RSA_FR1	4.955	101	104	2 gas boilers	3	radiators, AHU	storage, recirculation

3 Implemented solution

The technical solution was implemented through a comprehensive digital retrofit, bridging legacy HVAC systems and the functional requirements of BACS Class B [8], implementing the system architecture conceptualised in Figure 1.

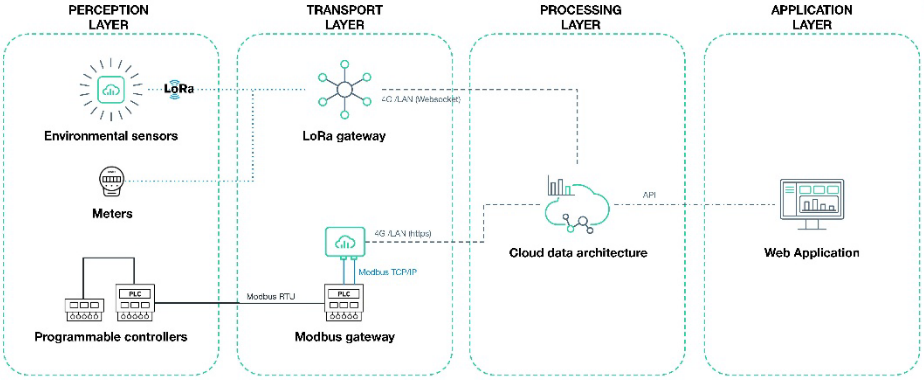

Fig. 1. General architecture of the implemented technical solution.

Budget constraints precluded the replacement of primary mechanical components, including thermal generators, pumping groups, and actuators. Therefore, the intervention focused on a digital upgrade, replacing obsolete control units with high-performance, expandable Programmable Logic Controllers (PLCs). By increasing the density of control points and integrating a greater number of analog and digital inputs/outputs compared with the previous system, the retrofit enables detailed supervision of both thermal generation and distribution systems. The PLCs establish a robust local control layer, ensuring service continuity and autonomous management of system redundancies and field-level anomalies. Core thermoregulation and safety functions are executed locally, while operational setpoints and schedules are dynamically adjusted by a cloud-based optimisation algorithm, transitioning from static control to a demand-oriented strategy.

The data transport layer employs a dual-gateway topology to ensure data persistence and reliable bidirectional communication between field-level controllers and the cloud platform. A primary field gateway acquires telemetry from the PLCs via Modbus RTU and forwards it to a secondary gateway over Modbus TCP/IP. This multi-tiered architecture enables secure data uplink to the cloud through multi-operator 4G IoT connectivity, operating independently of local IT infrastructure and mitigating cybersecurity and network compatibility risks.

To support optimisation, the cloud algorithm aggregates heterogeneous data, including PLC telemetry (temperatures, status registers, actuator feedback), gas meter pulses, and environmental LoRaWAN IoT sensors monitoring temperature, relative humidity, and CO_2 levels (“perception layer” in Figure 1). These multi-source inputs are processed to calculate optimised operational parameters, refining start/stop sequences and flow temperature setpoints for individual distribution circuits. Optimised values are transmitted back to the PLCs, which coordinate generator cascade modulation and pump operation accordingly.

At the application layer, each facility was integrated into a centralised Web Application serving as the primary Human-Machine Interface (HMI). The platform provides operators with management of operational calendars, real-time setpoint adjustments, and synoptic monitoring of environmental parameters and energy consumption trends.

Prior to the retrofit, hardware limitations and a lack of interoperability restricted the infrastructure to Class D (“Non-energy efficient”) performance. The introduction of high-performance PLCs and cloud-based optimisation enabled the BACS to reach Class B for most functions, achieving measurable energy savings despite continuous occupancy and high thermal inertia. As detailed in Table 2, the retrofit increased the automation class from C/D to B/A for primary control functions. Specific exceptions were made for terminal emission control, distribution pump modulation, and hydronic network balancing. Achieving Class B in these areas would have required invasive mechanical up-grades, such as installing Variable

Frequency Drives (VFDs) on all circulation groups and Pressure Independent Control Valves (PICVs) on all emitters. Considering the project budget and target Return on Investment (ROI), these interventions were deemed economically unsustainable.

The project rollout began in July 2024, with the commissioning mostly completed by December 2024, with the exception of site-specific operational delays and infrastructure complexities that postponed final commissioning in RSA_FR7 and RSA_FR8.

Table 2. BAC classes before and after implementation of the technical solution.

System	Control function	Pre-retrofit BAC class	Post-retrofit BAC class
Heating	Emission control	C	C
	Water temperature control in the distribution network	C	A
	Intermittent emission and/or distribution control	D	B
	Distribution pump control	C	C
	Hydronic balancing of the heating network	D	D
	Combustion generator control	D	A
	Sequential control of different generators	C	B
DHW	Storage temperature control using heat generator	D	A
	DHW pump control	D	B

4 Method of analysis

To verify the energy savings achieved thanks to the upgraded control strategy, the energy use of the facilities collected from January 2025 - first full month after the commissioning of the new systems - until August 2025, was compared to the historical heating energy consumption data made available by the Customer from 2015 to 2024, excluding the years with significant deviation from the rest of the dataset (e.g. 2020-2021- COVID-19 pandemic) or with null values.

The adopted calculation method, in line with the guidelines by the International Performance Measurement and Verification Protocol [9], involves the identification of a calculation-based energy model that describes the normal behaviour of a building's energy consumption, which can then be used as a baseline for comparison with the consumption measured after the implementation of a retrofit measure. The saving, or rather, the "avoided consumption", is determined by the difference between the post-retrofit measured consumption and the baseline energy model.

Pre- and post-retrofit energy use data were provided by the Customer in the form of reporting sheets compiled with the total building area and number of beds coupled with the monthly consumption figures taken from bills covering the period January 2015-August 2025. For 4 out of the 9 buildings (RSA_FR1, RSA_FR2, RSA_FR4, RSA_FR6), the implemented solution allowed the authors to also collect post-retrofit hourly gas consumption measurement data, enabling a deeper and real-time understanding of the energy consumption trends for these buildings.

To enable the comparison of monthly and hourly data available for the analysis, the energy data were all reduced to an average daily granularity: monthly data from bills were divided by the number of days in the corresponding month; hourly data were aggregated by day.

With the goal of deriving mathematical models describing the buildings' energy behaviour, the available heating consumption data were plotted against outdoor temperatures, from which pre- and post-retrofit energy signatures for each building were obtained.

The baseline energy model ($E_{baseline}$), describing the pre-retrofit typical energy use of the buildings (i.e. the pre-retrofit energy signature), was built using a linear equation with 2 parameters (Equation 1):

$$\mathrm{E_{baseline}} = \mathrm{C} + \mathrm{B} \cdot \mathrm{X} \qquad (1)$$

where,

B: Angular coefficient of the linear regression model, kWh/°C or kWh/(°C*h)
C: Constant term of the linear regression model, kWh
X: Independent variable in the regression model, °C or °C*h

The selected independent variable "X" was the hourly temperature difference cumulated over a day (HDH - Heating Degree Hours), calculated as per:

- Equation 2, in case of hourly energy data available (post-retrofit for buildings 1, 2, 4 and 6);
- Equation 3, in case of monthly energy data available (pre-retrofit for all buildings, post-retrofit for buildings 3, 5, 7, 8, 9).

$$\mathrm{HDH} = \textstyle\sum_{i=1}^{24} \max\,(21\text{-}\mathrm{T_{ext,i}};\, 0) \qquad (2)$$

$$\overline{\mathrm{HDH}} = 1/\mathrm{DM} \cdot \textstyle\sum_{i=1}^{\mathrm{DM}} \mathrm{HDH_i} \qquad (3)$$

where,

HDH: Cumulative hourly temperature difference (Heating Degree Hours), °C*h
T_{ext}: Outdoor temperature, °C
$\overline{HDH}$: Monthly average of the HDH values, °C*h
DM: Days of the month

Plotting the daily energy consumption data against the HDH referred to the pre-retrofit period enabled the definition of the known term C and the angular coefficient B for each building, thus creating the desired baseline energy models.

Once the post-retrofit energy consumption (E_{post}) and outdoor temperature data were available, they were reported with the same granularity and variable type ($HDH_{post} = X_{post}$) as the pre-retrofit data and projected onto the Energy saving equation (E_{saving}) given in Equation 4). The percentage saving was calculated by comparing E_{saving} e $E_{baseline}$, as per Equation 5.

$$\mathrm{E_{saving}} = \mathrm{C} + \mathrm{B} \cdot \mathrm{X_{post}}\text{-}\mathrm{E_{post}} \qquad (4)$$

$$\mathrm{Saving\%} = \mathrm{E_{saving}}/(\mathrm{C} + \mathrm{B} \cdot \mathrm{X_{post}}) \qquad (5)$$

For the 4 buildings for which post-retrofit field measurement data were available (RSA_FR1, RSA_FR2, RSA_FR4, RSA_FR6), a three-parameter discontinuous model (Equations 6.1 and 6.2) was used to model the post-retrofit energy signature, using both HDH and external temperature as independent variables X. The discontinuity of the model is linked to the use of boilers cascade configuration and is identified by the model in variable X_b, which represents external temperature or HDH.

$$\begin{cases} E_{\text{baseline}} = C_1 + B_1 \cdot X & \text{for gen and feb} \\ E_{\text{baseline}} = C_2 + B_2 \cdot \max\,(X_b\text{-}X;\, 0) & \text{from mar to aug} \end{cases} \qquad (6)$$

Based on the above premises, for the 4 buildings for which post-retrofit field measurement data were available, 3 energy savings assessment methods were applied:

- Pre-retrofit bill-related baseline energy vs. post-retrofit bill-related energy data plotted against HDH;
- Pre-retrofit bill-related baseline energy vs. post-retrofit hourly data-related energy data plotted against HDH;
- Pre-retrofit bill-related baseline energy vs. post-retrofit hourly data-related energy data plotted against average external temperature.

On the other hand, for the 5 buildings where it was not possible to install energy meters in the context of the implemented energy efficiency project, a single energy savings assessment method was applied:

- Pre-retrofit bill-related baseline energy vs. post-retrofit bill-related energy data plotted against HDH.

5 Results and discussion

The comparison of the pre-retrofit energy signatures and the post-retrofit ones shows a clear improvement in energy consumption after the implementation of the energy efficiency solutions that improved the BAC class control functions. The resulting energy savings are displayed in Table 3, ranging from a minimum of 9,5% up to a maximum of 45% reduction with respect to the corresponding baseline energy use. The best results were recorded for the buildings where post-retrofit hourly energy data were available: average thermal energy savings are 24% for RSA_FR1, 18% for RSA_FR2, 38% for RSA_FR4, and 44% for RSA_FR6. The lowest savings, instead, were observed in RSA_FR7 and RSA_FR8 - 9,5% and 16,8% respectively - primarily due to delays in the commissioning of the implemented projects, that limited system operation in January and February.

From Table 3 it is also evident that all the baseline energy models, based on bill-related data, have an R^2 between 0,5 and 0,6 (except for RSA_FR9, which is 0,34) and an average CV(RMSE) of 35%. This is probably because the regression was performed on overly aggregated data covering a long period of time (from a minimum of 5 to a maximum of 10 years). The high dispersion of pre-retrofit data suggests a former poor regulation of the heating system, caused by the absence of automatic control functions and incorrect use of the system.

Table 3. Summary of consumption and savings in French LTC facilities.

Buildings	Consumption from baseline (kWh)	Post-retrofit consumption (kWh)	Saving (%)	R^2	CV(RMSE) (%)	MAPE (%)
RSA_FR1	328.648	240.726	26,8	0,56	36,9	47
RSA_FR1*	284.754	226.602	20,4	0,57	36,8	47
RS_FR1**	283.722	216.056	23,8	0,57	36,8	47

Buildings	**Consumption from baseline (kWh)**	**Post-retrofit consumption (kWh)**	**Saving (%)**	**R^2**	**CV(RMSE) (%)**	**MAPE (%)**
RSA_FR2	615.993	440.150	28,5	0,63	33,1	62
RSA_FR2*	471.302	422.415	10,4	0,62	33,3	63
RSA_FR2**	538.546	451.305	16,2	0,63	33,2	62
RSA_FR3	382.966	305.714	20,2	0,66	36,2	35
RSA_FR4	479.606	295.802	38,3	0,67	30,9	25
RSA_FR4*	455.624	289.701	36,4	0,69	30,5	25
RSA_FR4**	478.171	295.732	38,2	0,67	31,4	30
RSA_FR5	600.738	448.344	25,4	0,53	43,4	52
RSA_FR6	496796	273.130	45,0	0,55	36,4	49
RSA_FR6*	494.096	283.792	42,6	0,56	36,3	49
RSA_FR6**	499.301	274.142	45,1	0,56	36,0	49
RSA_FR7	264.420	220.087	16,8	0,65	41,8	53
RSA_FR8	490.713	443.993	9,5	0,56	36,6	44
RSA_FR9	489.547	249.404	49,1	0,34	41,5	44

*The post-retrofit data comes from the Enerbrain database and is aggregated data with a daily timestamp, calculated by averaging the hourly data. The pre-retrofit data has been divided by the days of the month, obtaining the average daily consumption characteristic of each month.

** Post-retrofit data as in *, but plotted on average outdoor temperature instead of cumulative hourly temperature difference (*HDH*).

Figures 2, 3 and 4 report a meaningful example of the output of the analysis carried out for the buildings for which post-retrofit hourly energy use data were available, in this case referred to as RSA_FR1. Specifically, Figure 2 displays a scatter plot based on the monthly bill-related energy consumption data for both pre- and post-retrofit periods against HDH, Figure 3 shows the scatter plot populated using monthly bill-related energy data pre-retrofit and hourly energy data post-retrofit against HDH, and Figure 4 displays the same energy data as per Figure 3 plotted against external temperature. No matter the energy data granularity, nor the selected independent variable, the energy saving reductions are always evident.

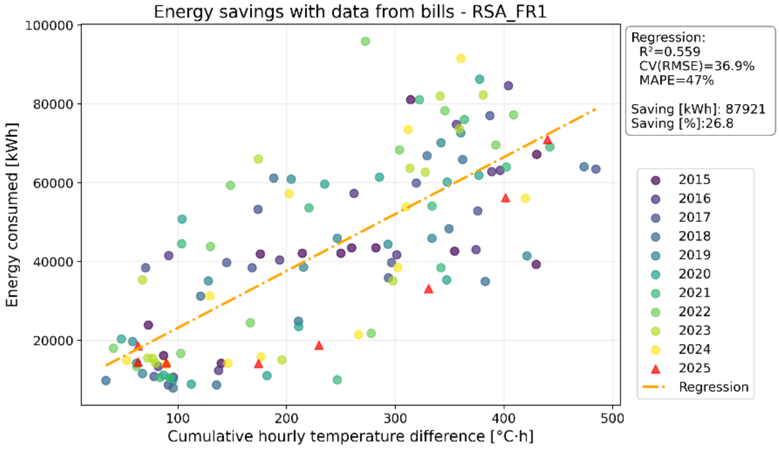

Fig. 2. Energy use (post-retrofit monthly bill-related data) plotted against HDH - RSA No. 1.

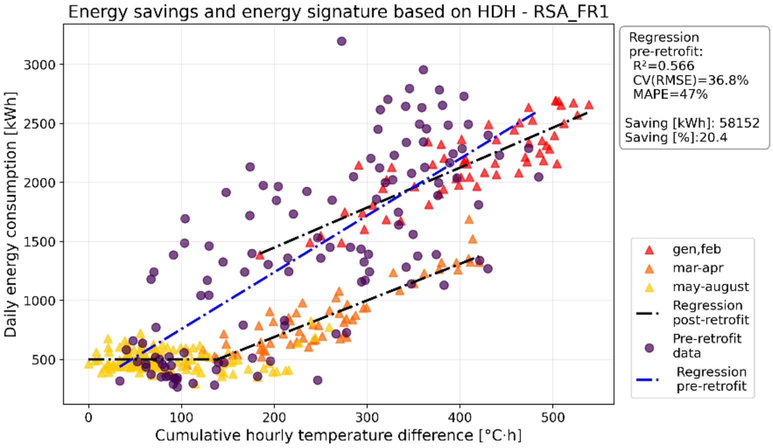

Fig. 3. Energy use (post-retrofit hourly energy data) plotted against HDH - RSA No. 1.

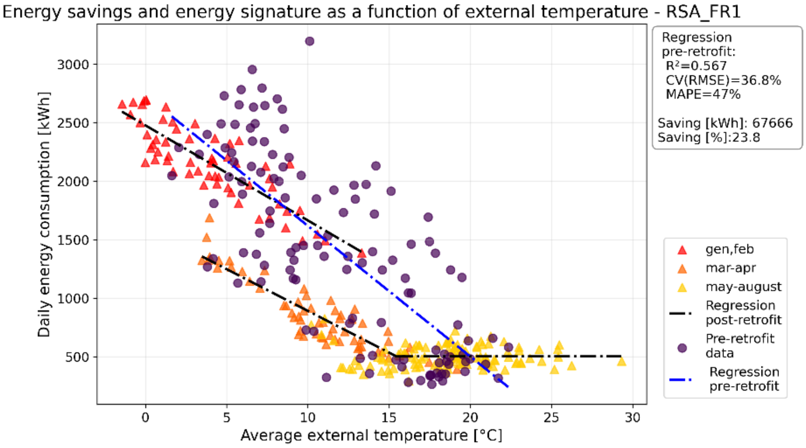

Fig. 4. Energy use (post-retrofit hourly energy data) plotted against external temperature - RSA No. 1.

A closer look at the post-retrofit data in Figures 2, 3 and 4 also reveals that the greatest savings were achieved with mild winter outdoor temperatures (corresponding to March, April and May), since the upgrade in the BACS class has untapped the energy saving potential of a dynamic regulation of the heating system. Similar trends were noticed in RSA_FR2 and RSA_FR6

Figures 3 and 4, thanks to the hourly granularity of the data available, also provide clear evidence of the energy models discontinuity due to the presence of the boilers cascade configuration, especially in the case of old equipment. The step change in the energy data plot in these graphs corresponds to the transition from February to March. This is justified by the presence of two 20-year-old boilers managed with a cascade logic, which provides for the use of the second boiler only if the first is delivering maximum power. Therefore, in the colder months, there is an upward shift in the line, resulting from the use of both boilers, while as the outdoor temperature rises, there is a downward shift in the line, due to the use of only one boiler. For higher outdoor temperatures (or low cumulative hourly temperature differences), the energy signature is constant and represents the gas consumption due to the use of DHW with storage and recirculation.

Figure 5, on the other hand, shows that, in the case of building RSA_FR4, no discontinuity caused by the cascade of boilers was detected. In this case, the boilers are more recent (10-years old) and the controller sends the setpoint to the master boiler, which manages the ignition of the slave boiler according to an already optimised internal logic. This avoids discontinuity in power generation and, therefore, in the energy consumption shown and in the resulting energy signature.

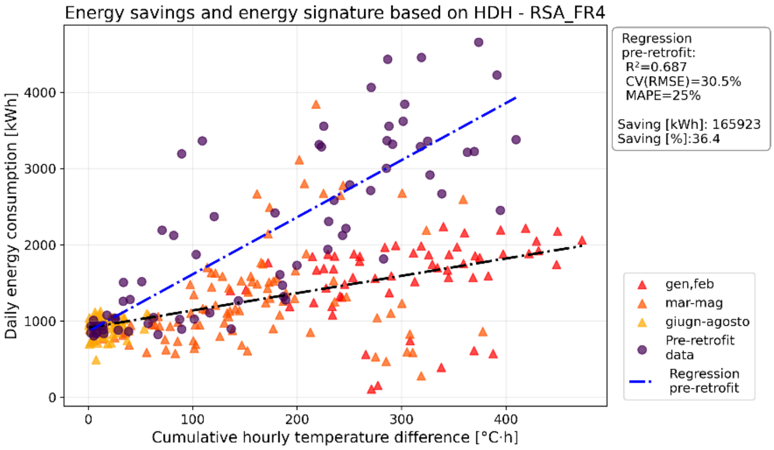

Fig. 5. Energy use (post-retrofit hourly energy data) plotted against HDH - RSA No. 4.

Figure 5 also displays very low or very high energy use data with respect to the energy signature. These points highlight a deviation from normal system operation, due to site maintenance operations or to a temporary increase in setpoints.

Finally, the energy signature of building RSA_FR6, displayed in Figure 6, provides an example of two kinds of discontinuities in the energy model: the former due to the presence of the boiler cascade, the latter due to the transition from winter to summer mode. The second discontinuity is caused by the change in setpoint made by maintenance technicians on the boilers during the seasonal switchover. From the graphs it can also be observed that in summer mode, the regression line is not as constant as in the previous case studies. This is because RSA_FR6 does not have a DHW storage tank, making generation more sensitive to changes in user demand.

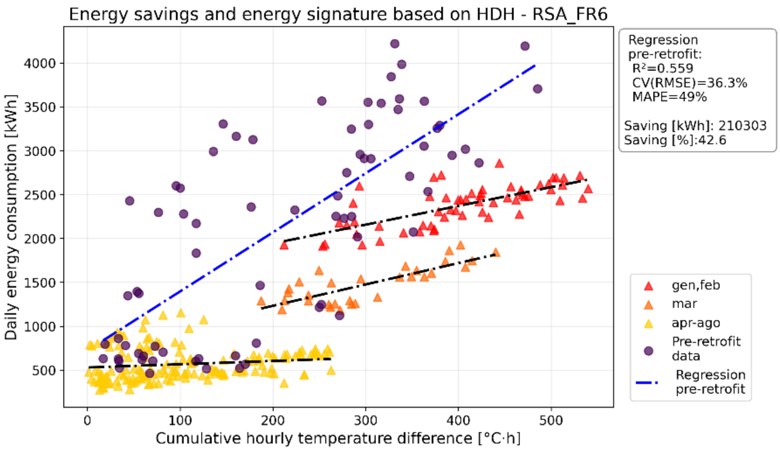

Fig. 6. Energy use (post-retrofit hourly energy data) plotted against HDH - RSA No. 6.

6 Conclusion

The results of this study demonstrate the effectiveness of cloud-edge HVAC systems architectures as a robust strategy to achieve substantial energy savings in healthcare facilities. Upgrading legacy HVAC control systems from BACS Class D to an optimised Class B configuration, in accordance with ISO 52120-1 [8], led to an average 29% reduction in heating Energy Use Intensity.

While these results acknowledge a degree of uncertainty due to the high dispersion of pre-retrofit baseline data, the post-intervention findings are highly promising; they provide empirical evidence of the impact of BMS-related retrofits and identify specific areas for further refinement in control strategies.

It is worth noting that in the facilities where the system architecture enabled the collection of hourly energy consumption data, the recorded savings were consistently higher. This suggests that real-time granularity not only facilitates a more precise measurement and verification process but also empowers more informed, proactive management of daily HVAC operations.

A final key takeaway concerns the practical feasibility and cost-effectiveness of comprehensive BACS upgrades. The technical challenge of improving three of the seven primary heating control functions (emission control, distribution pump control and hydronic balancing of the heating network) highlights that certain requirements of international standards may not always be economically or technically viable in existing buildings. Nevertheless, the results demonstrate that even a partial transition - upgrading from Class D to a performance level approaching Class B - can deliver substantial energy performance gains, thereby confirming the strategic value of cloud-based optimization for the decarbonization of the existing building stock.

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