Building monitoring system in a large social housing intervention in Northern Italy

Original
Building monitoring system in a large social housing intervention in Northern Italy / Sirombo, Elisa; Filippi, Marco; Catalano, Antonio; Sica, Andrea. - In: ENERGY PROCEDIA. - ISSN 1876-6102. - 140(2017), pp. 386-397.

Publisher:
Elsevier Ltd

Published
DOI:10.1016/j.egypro.2017.11.151

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 140 (2017) 386–397

Energy Procedia

www.elsevier.com/locate/procedia

AiCARR 50th International Congress; Beyond NZEB Buildings, 10-11 May 2017, Matera, Italy

Building monitoring system in a large social housing intervention in Northern Italy

Elisa Sirombo[a]*, Marco Filippi[a], Antonio Catalano[b], Andrea Sica[c]

[a] *Department of Energy, Politecnico di Torino, Corso Duca degli Abruzzi 24, Turin 10129, Italy*
[b] *Delta Controls Italy s.r.l, Via Monte Rosa 3, Milan 20149, Italy*
[c] *InvestiRE SGR SpA, Largo Donegani 2, Milan 20121, Italy*

Abstract

Within the framework of the well-known problem of the performance gap, the paper demonstrates how a building monitoring system is able to provide feedback data instrumental to address the ongoing management issues of multi-family buildings in social housing: the need to have a good understanding of what works and what does not in building operation, the need of bills controlling and allocation of individual costs between the occupants, the facility and energy management requirements including the understanding of occupant's behavior. It adopts a case study approach, discussing the case of a large environmentally friendly social housing intervention consisting in 323 flats, in which a building monitoring system was installed.

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings.

Keywords: performance gap; building monitoring; asset and operational rating; occupant behavior; energy management; facility management; energy savings; water savings;

---

1. Introduction

In Europe the energy consumption of the residential sector accounts for 25% on the overall building sector energy consumption. Considering the strict path established in the 2030 climate and energy framework at European level for reaching a 40% (below 1990 level) of CO_2 carbon reduction by 2030, strong efforts are needed into the adoption of actions for understanding the complexities related to the building actual operation. As widely reported in literature,

---

* Corresponding author. Tel.: +39-011-090-4552; fax: +39-011-090-4552
E-mail address: elisa.sirombo@polito.it

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings
10.1016/j.egypro.2017.11.151

buildings rarely perform as predicted during the design stage. The mismatch between the expectations around the energy performance of new buildings and the real energy bills has been addressed as " performance gap" [1,2]. A similar phenomena, addressed in literature as "rebound share" or "energy savings deficit", interests the refurbishment of existing buildings, where energy savings achieved in practice (and thus the reduction in CO2 emissions) due to building retrofit measures is lower than those calculated in engineering conservation studies [3].

Generally, the reasons causing the performance gap are categorized into three main groups: causes that pertain to the design stage, such as wrong assumptions in the energy models and inadequate predictions, causes rooted in the construction stage, such as difference between design and real construction, and causes that relate to the operational stage, such as not correctly operating systems as commissioned (including deficiencies in equipment installation and proper maintenance) or building occupants not behaving as supposed [4].

The minimization of the performance gap is a key issues in case of public-private social housing project where energy performance measures are a crucial driver of feasibility. It has been demonstrated that high energy performance of buildings is a leverage for the provision of affordable housing; lower energy bills turns into tenants willingness to pay higher rents, increasing economic benefits for the investor [5].

Given the state of the art, it is evident that bridging the gap between predicted and measured, especially when delivering high energy efficient building, is a complex problem that involve all the building industry chain. Lots of improvement opportunities can be found in each building delivery stage. But an emerging interest in the field of building performance monitoring has aroused. Efforts are increasingly underway to link prediction and measured data in integrated building information systems; while this does not necessarily bridge the gap, it at least works towards increasing the stakeholders (designers, users, facility manager, etc.) awareness about the problem. Refer for example to the CarbonBuzz project launched in 2008 by the Royal Institute of British Architects (RIBA) and the Chartered Institution of Building Services Engineers (CIBSE); it is a free online platform allowing practices to share and publish building energy consumption data anonymously, comparing that to predicted and benchmark values. A similar data gathering tool is Arc, an online where any project can participate and immediately start measuring energy and sustainability performance across any rating system or standard and benchmark against the industry values.

It's important to note that, as minimum energy requirement becomes more stringent, housing are becoming more complex in terms of installed engineering systems. In these cases, the building monitoring is strongly recommended [6], as it could provide objective data to:

- better understand the real performance of buildings monitoring the energy consumption, the behavior of occupants and their interaction with new technologies;
- assess the usability, reliability and acceptance of new technologies;
- address operation and maintenance activities.

In recent years, the implementation of building energy monitoring and management systems has been indirectly addressed by the European Directives, such as the Energy Performance of Building Directive recast (EPBD recast 2010/31/EU) and the Energy Efficiency Directive (EED 2012/27/EU). The first has encouraged the use of intelligent metering systems for new or renovated buildings; the latter has fostered the customer access to real-time and historical energy consumption data and has introduced for large companies energy audit obligations and annual energy reporting. In Italy, the D.lgs. 102/2014, in response to the EED 2012/27/EU, requires, in multi-family buildings, the installation of energy metering devices able to track the "voluntary" energy consumptions for heating, cooling and domestic hot water of individual units for energy costs allocation.

The selection of metering and environmental sensors can be a challenging task due to recent developments on accuracy, robustness, data storage, miniaturization, ability to connect using multiple communication protocols, integration with building energy management system and the Cloud [7].

Within this framework, the paper aims at presenting the implementation of a building monitoring system (BMS) installed in a large social housing intervention in Italy. The architecture and the capabilities of the BMS are presented, as well as possible outputs useful for energy management activities, allocation of the individual expenses and the occupant's behavior analysis.

2. The case study

The case study refers to the project “Borgo Sostenibile”, a large social housing intervention in Figino (near Milan) promoted by the real estate fund of InvestiRE SGR “Abitare Sociale 1”. It has been completed in 2015 and partially occupied till now.

It interests a large site for a total area of about 48600 m^2. Seven condominiums, for a total of 29400 m^2 of gross floor area house 323 flats, common auxiliary spaces (living room, laundry, storage room), 1325 m^2 of retail spaces, some offices and co-working spaces. Common outdoor amenities and utilities are available for inhabitants.

Fig. 1. Plan view of the case study.

The design team developed energy strategies aimed at reduce the energy consumption of the whole complex at the use stage.

Buildings are designed to achieve high energy performance in operation, reducing the heating and cooling demand, installing high energy efficient engineering systems and renewable energy technologies.

Apartment buildings have a surface to volume ratio between 0,5 and 0,6 and they are highly insulated. Main materials are concrete, bricks and tiles to provide high thermal mass to the building. Exterior walls have an average U-value of 0,25 W/m^{2}K, slabs on unconditioned spaces and roof 0,24 W/m^{2}K and windows 1,8 W/m^{2}K. Buildings are designed to maximize the solar access on winter and the solar control on summer.

External thermal insulation allows reducing the incidence of structural and material thermal bridges.

Each flat has radiant panels for heating and cooling, controlled by a single-zone programmable device.

Stairwell-centralized mechanical ventilation systems with active thermodynamic heat recovery supply fresh air to all flats served by the stairwell itself delivered by Clivet (Zephir model). In winter the system extracts exhausted air, from which recovers energy by means of a reversible heat pump and supply fresh air in occupied spaces at a comfort temperature at least equal to the indoor air temperature; in summer, fresh air is cooled and dehumidified. It is designed to operate continuously in constant volume mode (0,6 ACH), with no possibility of occupant control.

A system of underground closed-loop pipes distributes groundwater (supplied by four groundwater wells) to the seven local plants, one for each condominium that group two or more apartment buildings. Each local plants is made of a heat exchanger, transferring heat from groundwater to technical water in a closed loop. It serves two reversible heat pumps which supply hot and chilled water for heating and cooling and DHW as well. Therefore, the settlement is all-electric; no other energy sources are present.

Buildings are class A rated according to the Italian legislation D.Lgs. 192/05 e s.m.i. in effect at the time of construction, which took into account only the primary energy need for heating and domestic hot water (DHW).

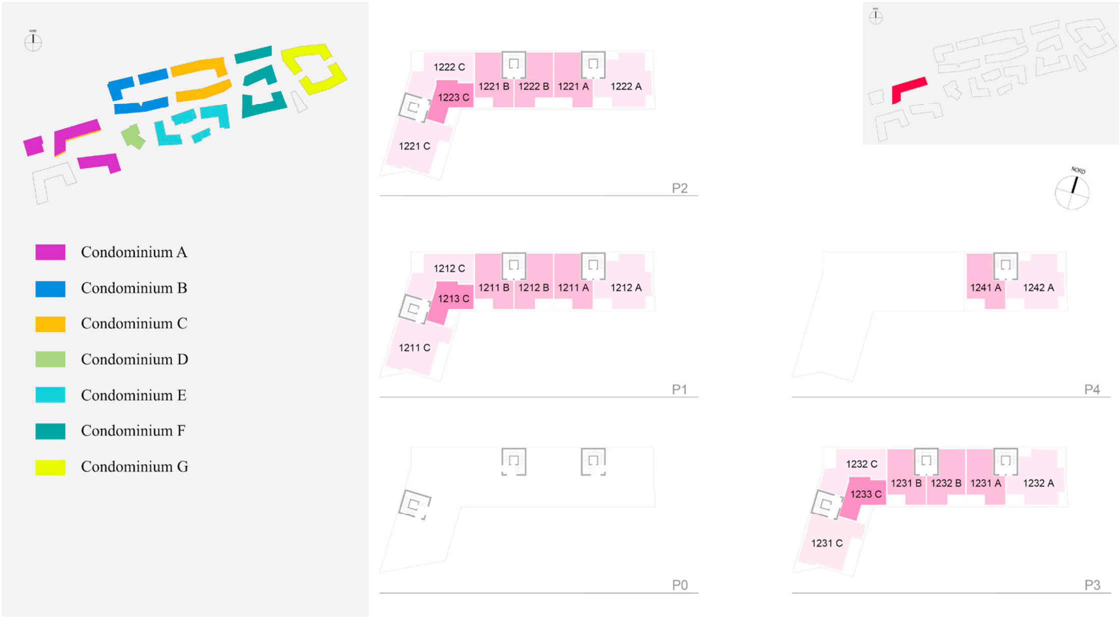


Fig. 2. Plan type of an apartment block of Condominium A. Each apartment building has one or more stairwells that serve more flats.

3. The building monitoring system

A Building Monitoring System (BMS) is installed and allows the real-time collection of consumption data of building related to uses of energy (heating, cooling, domestic hot water and ventilation) and water (hot and cold). Moreover, the actual status of the building system is recorded, including failures and deficiencies of the equipment.

The goal underpinning the development of the BMS was to verify the actual building consumption regard to the design (and expected) targets, to control and optimize the building system operation and to analyze the occupant behavior considering its strong influence on the energy consumption.

The BMS, delivered by Delta Controls, is based on the BACnet™ (Building Automation and Control Network) standard, an open communication protocol developed by ASHRAE in 1995. It was preferred to other proprietary systems in order to maximize the interoperability and the flexibility in designing and configuring the system also in the future. Interoperability creates an environment where building operators and managers might see all of their systems from one interface and take appropriate maintenance actions and control adjustments that have important energy implications.

3.1. BMS architecture and functionalities

Sensors and metering devices are physically located both at central (local plants) and local level (stairwells, flats, retail, etc.) to measure building performance parameters (e.g. thermal and electrical energy consumption, water consumption), indoor environmental parameters (air temperature and relative humidity) and temperature and flow rates of hot and chilled water. Table 1 reports the main technical features of meters and sensor installed for the purpose. The BMS also connect monitoring data (air flow, temperature, etc.) coming from on board sensors of the stairwell centralized mechanical ventilation units.

Table 1. Technical features of main installed metering devices or sensors.

Metering device	Measured parameters	Type of sensor	Measuring range	Class / Accuracy	Metering timestep
Electricity meter	Electrical energy	Digital multimeter and a transducer	10 -□500V rms (L-N) / 50mA -□5A rms	1	15 min
Electricity meter	Electrical energy	Digital multimeter and a transducer	3x220-240 VAC (-20% - +15%)	B	15 min
Thermal energy meter	Water flow / flow temperature	Woltman Counter and 2 Temperature Sensor connected to a MID Heat Meter	10-2500 l/h	EN 1434-1:2007 classe 3	2h
Water flow meter	Water flow	Woltman Counter	10-2500 l/h	+/- 5%	2h
Air temperature sensor	Air temperature	Thermistor	0-55°C	+/- 0,2°C	15 min
Air RH sensor	Relative humidity	Linear sensor	10-90% RH	+/- 3% RH	15 min

The BMS network is based on controllers and interface modules (gateways) connected by a flexible network such as to support a possible customization of the systems functioning and environments control. All devices are connected to each other with BUS RS-485 MS / TP connections, Ethernet and IP and can communicate without intermediaries. The communication infrastructure, operating with BACnet standard, always keeps connected the control and the management/display points, minimizing any disruption due to a bad communication. The network is organized with a top-down logic as follow:

- Local plants, which aggregates a series of parcel
- Parcel, which aggregates a series of apartment buildings
- Apartment buildings, which aggregates a series of flats and retail/office spaces
- Flats and retail/office spaces are the minimum control units

Figure 3 shows a conceptualization of the typical system architecture respectively of the local plants and flats.

An apartment BACnet controller MS/TP with user interface allows managing each flat independently by the occupant. By the device, the occupants can locally or remotely program the air temperature setpoints for different user-defined period of time (hourly, daily, weekly, monthly, etc.), switch on or off the heating/cooling system and control alarms as shown in Table 2. Moreover, the device allows monitoring and recording all the settings programmed by the users and the indoor air temperature and relative humidity. All these data are remotely accessible.

Table 2. Setting modes available for users.

Available settings	Possible actions
Automatic Comfort	Set the air temperature set points in case of presence of the user
Temporary Comfort	Set the air temperature set-point and the period of time in which the heating/cooling system is turned on (in case of presence of the user)
Forced Comfort	Set the comfort mode defining a air temperature set point without limiting the period of time in which the heating/cooling system is turned on (in case of presence of the user)
Automatic Eco	Eco mode is useful to set the system in case of absence of user. In automatic Eco mode, the user set the air temperature set points
Temporary Eco	Set the air temperature set-point and the period of time in which the heating/cooling system is turned off (in case of absence of the user)
Forced Eco	Set the Eco mode defining a air temperature set point without limiting the period of time in which the heating/cooling system is turned off (in case of presence of the user)
Turning off	The heating and cooling system is turned off, except for the antifreeze protection in winter.

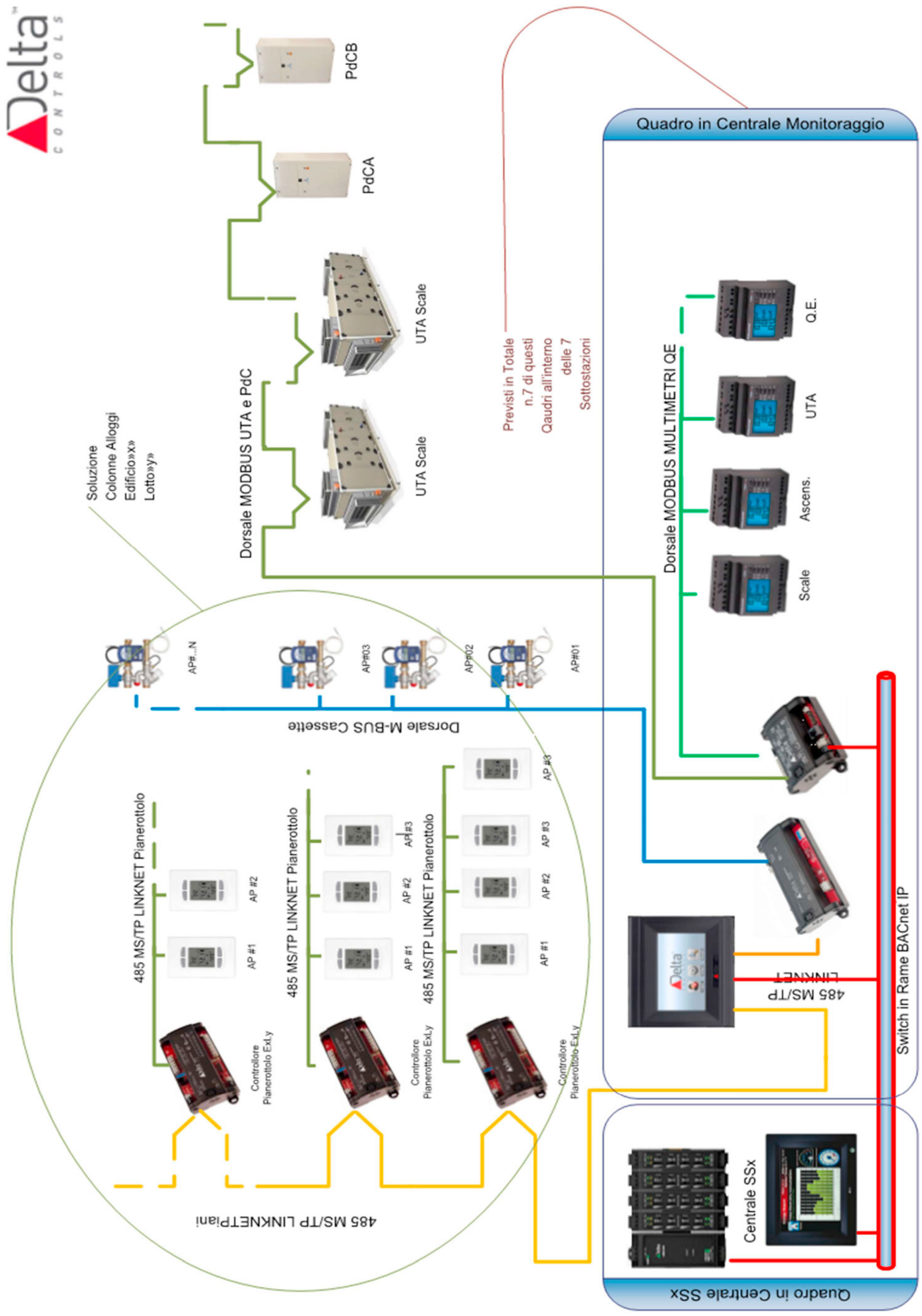


Fig. 3. Scheme of the BMS architecture

The information related to each flat come to another BACnet controller at floor level that deals with the thermal energy and water meters. All flats and floors level controllers are concentrated at the scale level and then to central plant controllers that manage the hot and chilled water production including also all data read via M-BUS on the Heating/Cooling metering consumption boxes. All information is made comparable at BACnet level, bringing into communication the production side (local plant) and the demand side (flats) to allow an energy efficient control of the heating and cooling system.

For each building and local plant, the consumptions of electrical energy are metered by digital multimeters via MODBUS RTU in a BACnet device and converted in BACnet objects. In each local plant a control panel is present. It is made of a native BACnet controller B-BC level with adequate number of I/O (on average about 180 for each local plant), a BACnet controller B-OD level with touchscreen and a BACnet controller/gateways able to acquire by installed multimeters, the electrical physical quantities related to various energy uses (AHU, elevators, lighting, etc.). The devices are all remotely or locally programmable, allowing a real time control of the system functioning. Moreover at any moment it is possible to change the algorithms, which control the sequences of operations of each system component and their integration.

The BMS is based on a distributed computing platform and remotely managed by means of standard web browser (no specific applications have to be installed). It is accessible simultaneously to an unlimited number of users, via Internet by a customer VPN.

3.2. Collected data

An energy and cost management team (E&CM team), which is composed by the project manager of the intervention, the facility manager and experts in the field of energy, is responsible of the data collection and analysis.

All the data collected on site from the different subsystems via standard protocol M-BUS and MODBUS are converted in BACnet objects in order to be stored on a web-computing platform and made accessible through a specific energy management software (EnteliWEB 2.2). It provides the E&CM team with customizable energy management dashboards, task-driven alarms, system dashboards, reports, etc., to visualize in real time the building systems performance, analyse historic data and remotely manage the facility. So that, the energy manager and the facility manager are assisted in the definition of possible optimizations of the building system operation due to the identification of decreases of efficiency and failures, while the building manager is assisted in cost controlling and cost allocation of individual expenses according to the national standard UNI 10200 [8].

The installed BMS is able to provide a clear picture of all building-related energy usage. Below, a synthetic description of the main available output data at different levels is reported.

By means of a series of BACnet controllers and M-BUS communication protocols, for each flat the data collected are:

- Thermal energy consumptions for heating and cooling, derived from thermal energy meters located on the supply side of the distribution of the floor radiant system as in Figure 4;
- Indoor air temperature and relative humidity derived from sensors installed within the conditioned volume;
- Settings of the control devices present in each flat, as set up by the occupants, as in Figure 5;
- Volume of hot and cold water consumed, derived from a water meter installed on the supply pipes. The DHW demand in kWh is conventionally calculated multiplying the hot water volume consumed (l) by a factor of 0,038 kWh/l; it is derived considering an average temperature difference of 33°C between the temperature of water supplied by the watermain (15°C) and the temperature of DHW produced by the heat pump (48°C).

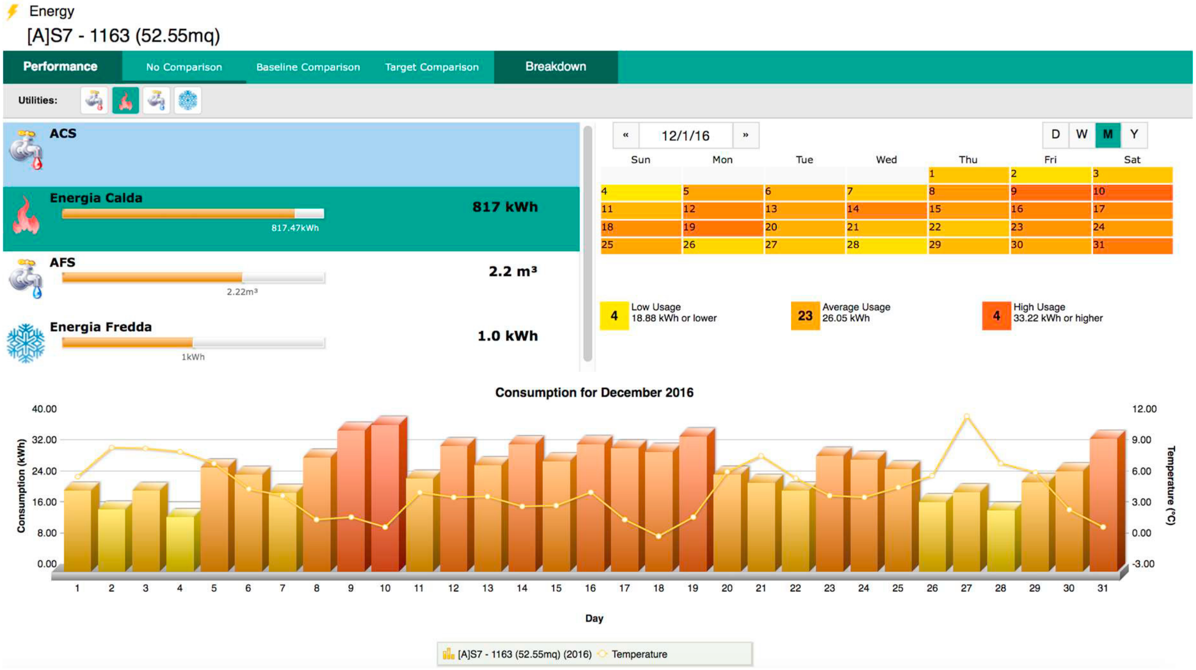
For each stairwell data collected regards the electricity consumption for elevators, lighting and ventilation, which includes both the electricity for fans (air circulation) and for packaged heat pumps (air treatment). Figure 6 show an example of the electrical energy breakdown for the stairwell 6A of condominium A in December 2016.

For each local plant a series of multimeters separately meter the electricity consumed by each heat pump and the total electricity consumed by auxiliary components, mainly water circulation pumps.

Additional multimeters record the electricity consumption of pumps, which serve the groundwater loop.

Through metered consumption data, dedicated software allows to calculate the allocation of energy costs between the occupants. Both voluntary and involuntary costs are calculated according to the above-mentioned standard UNI 10200.

Moreover, the BMS records the status of all the mechanical equipment installed (Figure 7), in order to track the functioning of the overall building systems. Alarms are set in case of disruptions or malfunctioning and automatic communications are sent to the O&M building manager.



[A]S7 - 1163 (52.55mq)

ACS

Energia Calda 817.47kWh 817 kWh

AFS 2.22m³ 2.2 m³

Energia Fredda 1kWh 1.0 kWh

12/1/16

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

4 Low Usage 18.88 kWh or lower

23 Average Usage 26.05 kWh

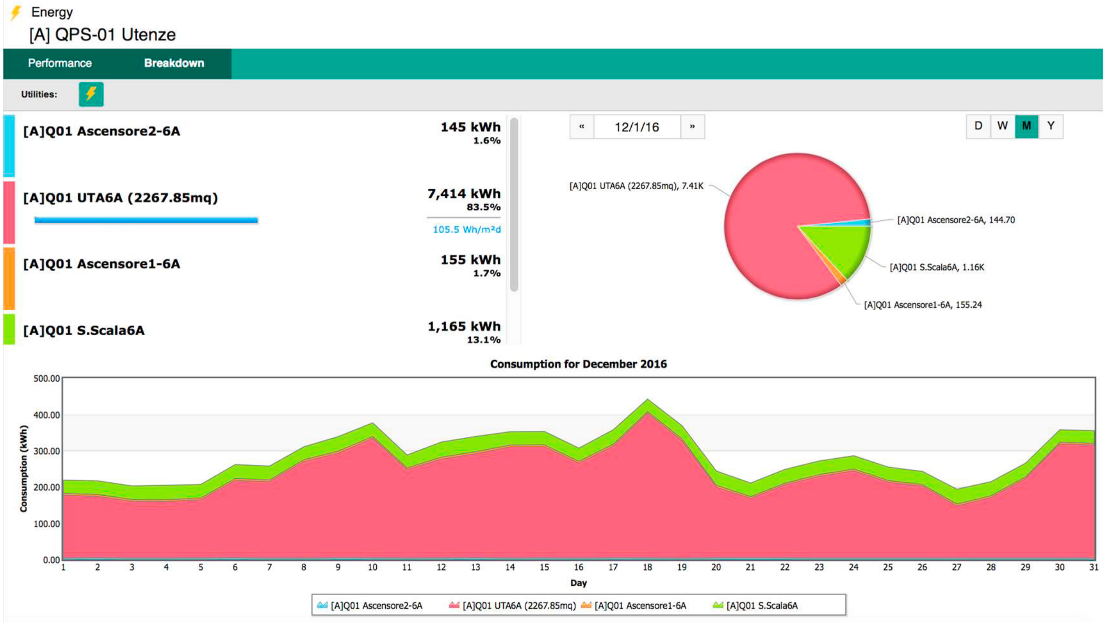
4 High Usage 33.22 kWh or higher

[A]S7 - 1163 (52.55mq) (2016)

Fig. 4. Example of thermal energy demand for flat 1163 located in condominium A. Screenshot of Enteliweb.

#	N.P.	S.C.T.	C.	N.C.	MODALITÀ	PRESENZA	TIPO CAL.	T. INTERNA [°C]	UR [%]	BLOCCO DA UR	STP. CORRENTE [°C]	STP. RISC. PRESENTE [°C]	STP. RAFF. PRESENTE [°C]	STP. RISC. ASSENTE [°C]	STP. RAFF. ASSENTE [°C]
1	2301A	503	C	14A	Presenza forz.	Presente	Semplice	20.8	23.5	No	22	21	25	16	33
2	2311A	503	C	14A	Auto	Presente	Semplice	20.5	44.2	No	21	21	25	16	33
3	2312A	503	C	14A	Auto	Presente	Semplice	20.8	32.5	No	22	22	25	16	33
4	2321A	503	C	14A	Presenza forz.	Presente	Semplice	22	30.6	No	22	21	25	16	33
5	2322A	503	C	14A	Presenza forz.	Presente	Semplice	19.8	33.1	No	22	21	25	16	33
6	2323A	503	C	14A	Presenza forz.	Presente	Semplice	22.2	24.8	No	22	21	25	16	33

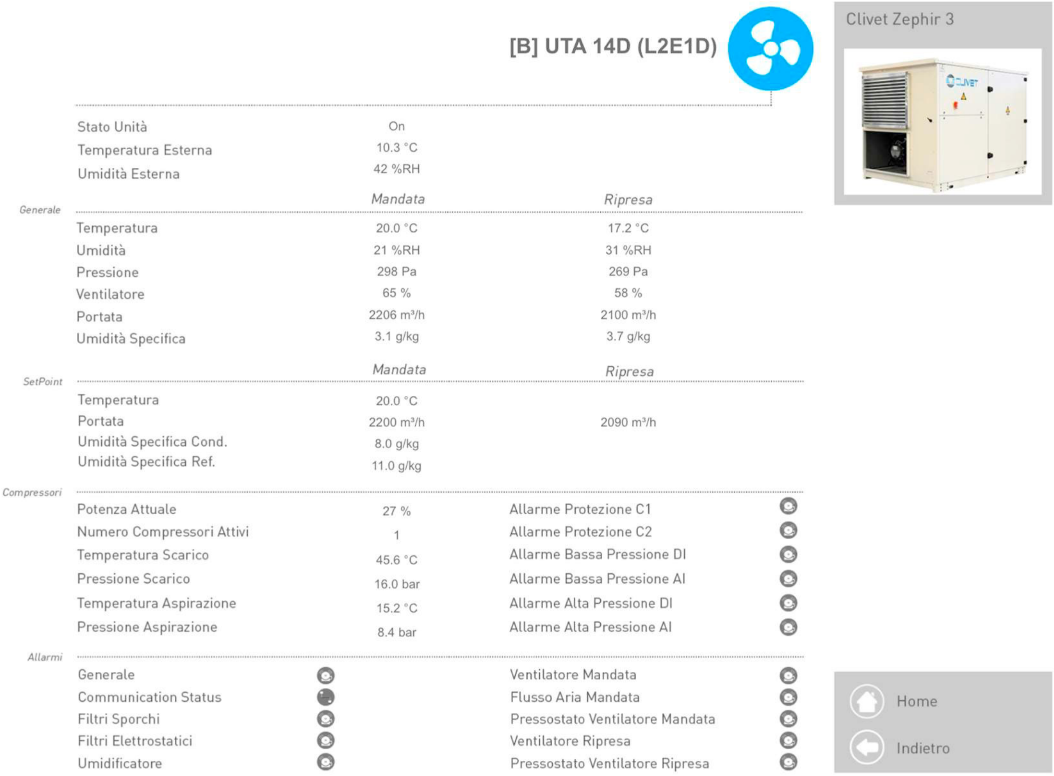
Fig. 5. Example of setpoint settings in some flats as registered by the BACnet control devices



[A] QPS-01 Utenze

[A]Q01 Ascensore2-6A	**145 kWh**	**1.6%**
[A]Q01 UTA6A (2267.85mq)	**7,414 kWh** 105.5 Wh/m²d	**83.5%**
[A]Q01 Ascensore1-6A	**155 kWh**	**1.7%**
[A]Q01 S.Scala6A	**1,165 kWh**	**13.1%**

Fig. 6. Example of monthly electrical energy consumption for elevators, ventilation and lighting for stairwel 6A, condominium A. Screenshot of Enteliweb.



[B] UTA 14D (L2E1D)

Stato Unità	On	
Temperatura Esterna	10.3 °C	
Umidità Esterna	42 %RH	

Generale	Mandata	Ripresa
Temperatura	20.0 °C	17.2 °C
Umidità	21 %RH	31 %RH
Pressione	298 Pa	269 Pa
Ventilatore	65 %	58 %
Portata	2206 m³/h	2100 m³/h
Umidità Specifica	3.1 g/kg	3.7 g/kg

SetPoint	Mandata	Ripresa
Temperatura	20.0 °C	
Portata	2200 m³/h	2090 m³/h
Umidità Specifica Cond.	8.0 g/kg	
Umidità Specifica Ref.	11.0 g/kg	

Compressori			
Potenza Attuale	27 %	Allarme Protezione C1	○
Numero Compressori Attivi	1	Allarme Protezione C2	○
Temperatura Scarico	45.6 °C	Allarme Bassa Pressione DI	○
Pressione Scarico	16.0 bar	Allarme Bassa Pressione AI	○
Temperatura Aspirazione	15.2 °C	Allarme Alta Pressione DI	○
Pressione Aspirazione	8.4 bar	Allarme Alta Pressione AI	○

Allarmi			
Generale	○	Ventilatore Mandata	○
Communication Status	●	Flusso Aria Mandata	○
Filtri Sporchi	○	Pressostato Ventilatore Mandata	○
Filtri Elettrostatici	○	Ventilatore Ripresa	○
Umidificatore	○	Pressostato Ventilatore Ripresa	○

Fig. 7. Example of instantaneous operational status report for a stairwell centralized mechanical ventilation unit. Screenshot of Enteliweb.

4. Data analysis for building management

The IT platform is structured to support three main objectives: the energy and water management, the facility management and the operation and maintenance (O&M) activities, as in Table 3.

Table 3. Examples of tasks, which can be performed through Enteliweb.

Aim	Tasks
Energy Management	Verify energy consumption of each flat, stairwell, condominium and of the whole settlement
	Compare actual energy consumption and costs between each other and between reference values (design targets, benchmark values or historic data)
Water Management	Verify water consumption of each flat, and water for irrigation and cleaning of common areas
Facility Management	Verify the functioning and disruptions of both building systems and specific mechanical equipment
	Check the alarms
	Verify the quality and the effectiveness of the O&M activities
Property Management	Analyse the operational costs in detail and allocate the costs between users

For energy management purposes, it is possible to analyse metered data, according to the following main objectives:

- check the operational energy rating of each flat, taking into account the actual energy use for heating, cooling, DHW and ventilation compared to the design targets;
- assess the consumptions of DHW
- verify the seasonal energy efficiency of building systems and equipment in order to better understand the real performance
- define reference values based on actual data for future comparison
- minimize the energy costs due by the users
- understand the occupant behavior in managing local control system to address education programs for occupants.

All the collected data are properly analyzed, allowing understanding both the energy consumption of buildings and the main factors influencing it, such as climate, building services and energy systems efficiency, building operation and maintenance and indoor environmental quality provided. They correspond to four of six main factors affecting energy consumption of buildings, as reported in IEA Annex 53 “Total Energy Use in Buildings: Analysis & Evaluation Methods”; the other two are the building envelope and the occupant’s activities and behavior [9].

The main Key Performance Indicators (KPIs) are the following [10]:

- thermal energy demand for heating, cooling and DHW of each flat, normalized per building size (square meter of net floor area). Normalization by weather data can be done when comparing actual values with design target values or historical data;
- electrical energy consumption for ventilation at stairwell level, normalized by square meter of served net floor area per day;
- seasonal energy efficiency “ε” of the energy systems calculated as the ratio of the sum of useful energy output (heating, cooling and DHW as measured by the metering devices of each flat) to the electrical energy input of the related heat pumps in the local plants;
- actual heating degree days for each flat referred to the winter season;
- indoor air temperature and relative humidity in each flat referred to the summer season.

When the minimum occupancy rate will be at 80%, and the operation of buildings will be similar to the design assumptions, it will be possible to begin effectively the energy management activity.

Example analysis reported below are based on data related to condominium C at the first year of occupation; occupancy rate was equal to 52% and the building systems were subjected to tuning activities. The aim is to present the opportunities related to such a BMS, not to analyse the actual performance of the case study reported.

Figure 8 reports the actual thermal energy demand for heating and cooling of each occupied flat of condominium C, normalized per net floor area in winter and summer periods (respectively 2015 October 15th –2016 October 14th and 2016 June 15th 2016 September 15th). Continuous lines represent the average values, equal to 54,5 kWh/m2 for heating and 11,3 kWh/m2 for cooling.

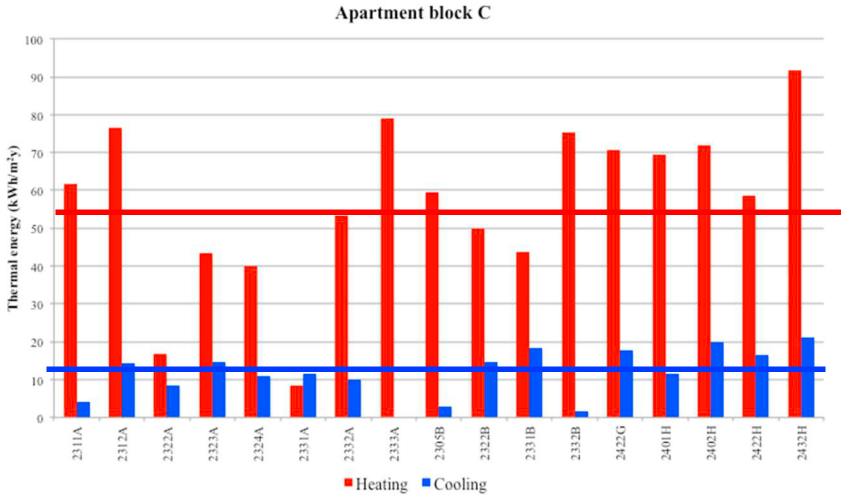


Fig. 8. Thermal energy consumption for heating and cooling of occupied flats in apartment Block C

The average value of the measured heating energy demand seems too high in comparison with the calculated standard value (44,9 kWh/m^2) and the consumption of each flats are highly variable around the average. It is important to note that the measured indoor air temperature in winter season was on average 1,1°C higher than 20°C, causing a major consumption of 12% than the expected. Detailed investigations are underway to understand the reasons, with a specific focus on the occupant's behaviour.

For water management purposes, the main KPIs are the daily total water consumption per person and the daily DHW consumption per person as related to the thermal energy demand of each flat. For example, for condominium C the average daily water consumption is 120 l/p, of which the DHW consumption is 54 l/p. The last one is greater than that calculated with Standard UNI TS 11300-2 [11], equal to 41,3 l/p.

For what concerns the verification of the operational functioning of the mechanical equipment, it is reported an analysis carried out on the stairwell mechanical ventilation units with thermodynamic heat recovery. From the first occupation of the building, the installed BMS showed a very high electrical consumption for ventilation, ranging from 16,7 to 52,3 kWh/m^{2}a.

A detailed analysis of the operational parameters of the air-handling unit, carried out in accordance with the manufacturer of the equipment, revealed that the main reason of the high consumption was the frequent defrosting caused by the too low humidity of the extraction air. Considering that in residential building, especially if not fully occupied, the low humidity of the indoor air is a typical situation in winter, the use of such units is not recommended in similar applications.

5. Conclusions

The paper describes a case-study application of a BMS in a large social housing intervention. It has been demonstrated how it can be instrumental to address a series of key objectives for building and facility managers and

E&CM team: the need to have a good understanding of what works and what does not in building operation, the need of bills controlling and allocation of individual energy costs between the users, the facility, energy and water management requirements including the understanding of occupant's behavior. Moreover it is an important tool to assess the effectiveness of installed building systems, in terms of reliability, user acceptance, etc.

The first year of occupancy has demonstrated that the advantages of having installed such a building monitoring system compensate the extra-costs of construction due, which can be approximately evaluated in 0,5% of the total construction costs. For that reasons, InvestiRE SGR is interested in embedding building performance monitoring in future interventions, as standard practice. Monitoring data from future interventions will be merged in the same web platform. A unique energy dashboard, which includes all the monitored building managed by InvestiRE, will be available to facilitate comparison and energy and facility management activities.

Related to the specific case study, major findings are as follow.

In consideration of the limited operational functioning of the mechanical ventilation units with active thermodynamic recovery due to the thermo hygrometric conditions of the return air, this technology is considered unsuitable for residential applications.

Thermal energy demand for heating of each flat is on average greater than expected and, compared between each other, a great variability has been observed. Further investigations on different directions, will be carried out: assessment of the actual heating degree days and set points set by the users; verification of the occupant behavior for what concern window openings and natural ventilation; analysis of the heat through the building envelope and via air infiltration, internal and solar gains of each flat; verification of the proper calibration of thermal energy meters.

The total water consumption are aligned with reference values in literature (e.g. UNI/PdR 15.1:2015 [12]), but DHW consumption seems to be on average greater than the value calculated according to the standard UNI TS 11300-2 for the assessment of the energy need for DHW. Further investigations will focus on the analysis of occupant habits and family types and verification of the proper calibration of some water meters.

Extended education actions will be organized to increase the occupant awareness about their energy and water consumption and the possibility to reduce them.

References

[1] Carbon Trust. 2011. Closing the gap: lessons Learned on Realizing the Potential of Low Carbon Building Design. Carbon Trust, London. Available form: https://www.carbontrust.com/media/81361/ctg047-closing-the-gap-low-carbon-building-design.pdf (Accessed January 2017)

[2] Menezes A.C., Cripps A., Bouchlaghem D., Buswell R.. 2012. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. Applied Energy, 97, 355-364

[3] Galvin R. 2014. Making the 'rebound effect' more useful for performance evaluation of thermal retrofits of existing homes: Defining the 'energy savings deficit' and the 'energy performance gap'. Energy and Buildings, 69, 515-524

[4] Wilde P. 2014. The gap between predicted and measured energy performance of buildings: A framework for investigation. Automation in Construction, 41, 40–49

[5] Copiello S. 2016. Leveraging energy efficiency to finance public-private social housing projects. Energy Policy, 96, 217-230

[6] Calì D., Osterhage T., Streblow R., Müller D. 2016. Energy performance gap in refurbished German dwellings: Lesson learned from a field test. Energy and Buildings, 127, 1146-1158

[7] Ahmad M.W., Mourshed M., Mundow D., Sisinni M, Rezgui Y. 2016. Building energy metering and environmental monitoring – A state of the art review and directions for future research. Energy and Buildings, 120, 85-102

[8] UNI. 2015. Impianti termici centralizzati di climatizzazione invernale e produzione di acqua calda sanitaria - Criteri di ripartizione delle spese di climatizzazione invernale ed acqua calda sanitaria. UNI 10200 Standard. Ente Italiano di Normazione

[9] Yoshino H. 2013. Final Report. IEA EBC Annex 53. Total Energy Use in Building: Analisys & Evaluation Methods

[10] Filippi, M. Corgnati, S.P., Caldera, M. "Energy demand for space heating through a statistical approach: application to residential buildings", Energy and Buildings 40/10 (2008): 1972–1983

[11] UNI. 2014. Prestazioni energetiche degli edifice. Parte 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale, per la produzione di acqua calda sanitaria, per la ventilazione e per l'illuminazione in edifici non residenziali. UNI TS 11300-2. Ente Italiano di Normazione

[12] UNI. 2015. Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità. UNI/PdR 15.1:2015. Ente Italiano di Normazione