Energy efficiency and occupants' behavior: analysis of a public housing case study

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SUMMARY

Energy management of buildings comprises quantitative technical aspects and social aspects related to the behavior of the inhabitants. Both play a crucial role in terms of energy use, emissions, and indoor comfort. In retrofits, the technical aspects are generally developed with skill and care by the designers and construction companies, while the aspects related to informing and sharing with the inhabitants are almost always neglected, often affecting the results of the work. The present study analyses the interaction of technical and behavioral aspects in a public residential building (ERP) with a social rent, located in the outskirts of Milan, which has recently undergone an important energy retrofit by the Municipality. The building houses about 500 tenants from 32 different countries, distributed over 154 apartments. Here, the EnerPOP project, funded by Politecnico di Milano, is developing a methodology for reconciling technical and social aspects in the context of the refurbishment of ERP assets. Energy use and comfort conditions have been evaluated in a number of apartments. The analysis shows a great variability in energy use and a poor correlation between that use with internal comfort conditions. Hypotheses of correlation between energy use and practices adopted by the tenants have therefore been formulated, thanks to a preliminary activity of social characterization of the resident families.

Key words: energy savings; energy refurbishment; indoor air climate monitoring.

1. INTRODUCTION

In recent years, the energy refurbishment of public buildings has become a priority for many municipal administrations throughout Italy, in order to comply with the objectives, set by the European Union to reduce greenhouse gas emissions by 20%, by 2020, compared to 1990, and thanks to the support of a national funding scheme, such as "Conto Termico". In the face of substantial economic investments in the planning, implementation and management of interventions, and of a European and national attention to the technical-economic optimization (Zangheri et al., 2018), there are critical aspects that are not usually taken into consideration in an appropriate manner, but which tend to reduce the amount of energy savings actually achieved by projects. One of the factors that contribute to obtain lower energy savings than expected, well known in the literature as "rebound effect" (Atkinson et al., 2016), is usually associated with changes in the behavior of users towards more energy-intensive lifestyles, in part connected to poor information and involvement in the refurbishing process. The rebound effect is declined in very different ways depending on various factors, including the social context, the degree of technological innovation of the solutions adopted in the refurbishment, the configuration of properties (public or private, rental or home ownership) (Sousa Mointero et al., 2017).

The EnerPOP project, funded by pre-tax donations for Politecnico di Milano, aims to analyze the technical and social aspects in the context of the retrofit of public residential buildings, in order to identify the causes of the gap between the expected (calculated) energy savings and the actual (measured) ones, and to propose options to reduce it. This gap is actually a number affected by uncertainty (if we take into account that both the calculated value and the measured value are affected by uncertainty), which may in certain cases constitute a significant percentage of the expected calculated value and therefore be in itself significant (Figure 1).

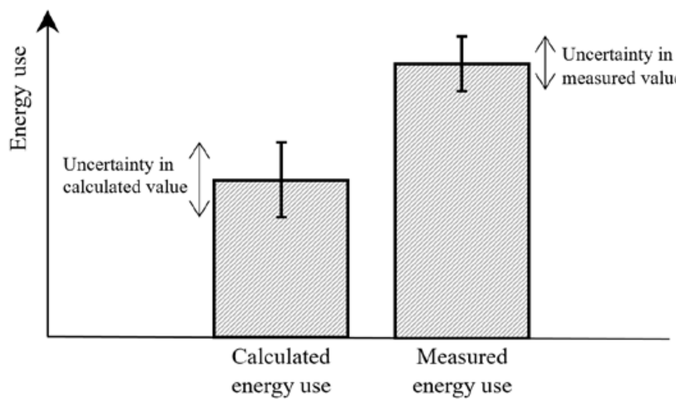

Figure 1 – The uncertainties in the calculated and in the measured energy use affect the estimation of the performance gap.

Various elements contribute to determine it: the differences between the project and the real building "as built", the difference between the climate adopted in the simulations and the real climate (Erba et al., 2017), differences between the design comfort conditions and those set in practice by the building manager and/or by users (Sfakianaki et al., 2011), inappropriate management by users of active and passive systems and their controls (when they are equipped with them), etc. (Elsharkawy et al., 2015).

The present study, developed as part of the EnerPOP project, fits into the context of public housing in the Municipality of Milan, counting a total of about 66 thousand public houses, of which 28 thousand are owned by the Municipality and managed by Metropolitana Milanese SpA (MM) (investee company of the Municipality of Milan) and 38 thousand are owned by ALER (Azienda Lombarda Edilizia Residenziale) and managed by ALER itself. About 25 thousand families live in public housing in Milan, for a total of about 51 thousand tenants (MM SpA, 2017), of which about 17% are foreigners and 33% are over 65 years old.

Between 2015 and 2017, the Municipality of Milan invested about 180 million euros for ordinary and extraordinary maintenance of public residential buildings, of which approximately 50 million euros specifically dedicated to energy efficiency measures. The building considered in this work is part of this type of actions, dating back to 2013 and therefore representative of a situation in which the effects of the enacted measures can already be considered fully operational, both from a technical point of view (commissioning already widely occurred, in theory) and as social one (community of tenants largely consolidated). The present study, starting from a real monitored building, presents the critical issues emerged in the case and, with a taxonomic approach, tries to obtain results related to the case under analysis, but also potentially generalizable.

2. DESCRIPTION OF THE CASE STUDY

The case study is a large public residential building (ERP), owned by the Municipality of Milan, located in a context of marked urban and social periphery. The building consists of five floors above ground, with 154 apartments, about half of which are small two-room apartments of about 40 m^2, and the rest four-room apartments with a surface ranging from 65 m^2 to 85 m^2, for a total of about 11 000 m^2 of gross floor area (Figure 2).

Since 2013, the building has undergone a major energy refurbishment and removal of asbestos, carried out by the Municipality of Milan with co-funding from the European Commission, in the framework of the European project EU-GUGLE (2013) and a contribution from the national incentive scheme “Conto Termico”. The original building was characterized by poor energy performance of the envelope and by obsolete mechanical systems, with resulting thermal discomfort (low air temperatures and radiant temperatures in winter) and low air quality (diffuse presence of mold). The renovation work focused first on improving the quality of the envelope and on the renewal of the heating system, with the centralization of hot water production as well as heating, followed by the connection to the district heating network. In each apartment a chrono-thermostat and thermostatic valves have been installed on the radiators, for control purposes only (billing is not based on individually metered consumption). A centralized mechanical ventilation system has also been installed, which operates in extraction only, with extraction vents placed in the bathrooms and fresh air entering the apartments through intake vents placed on the façade. The system works with constant flow and at low speed.

In 2014, at the end of this first phase of the works, the apartments were progressively assigned to the tenants; however, the families were not the same ones previously occupying the building. At present, the community that resides in the building consists of about 500 people, mostly elderly Italians and families of first-generation immigrants. 30% of the inhabitants are under the age of 15 – a particularly young community compared to the average of the public housing in Milan. 60% of the families are foreign, including more than 30 different nationalities. In all families, at least the head of the family is able to speak Italian.

Complementing the energy savings achieved during the first phase of the works, in 2016 a further retrofit measure was undertaken, with innovative characteristics compared to the standard renovations of public buildings in Italy. The new system allows the recovery of heat from the air extracted from the rooms, through the mechanical ventilation system, conveying it on the evaporator of an air-water heat pump that preheats the water of the aqueduct, upstream of the domestic hot water circuit. Photovoltaic panels were also installed to supply electricity to the above-mentioned heat pump and to the common parts of the building (thus becoming the first public residential building with photovoltaic panels in Milan). In 2014 the building was certified "class B" according to the Italian energy performance classification, with a calculated total primary energy use for heating of 34 kWh/(m^2 yr).

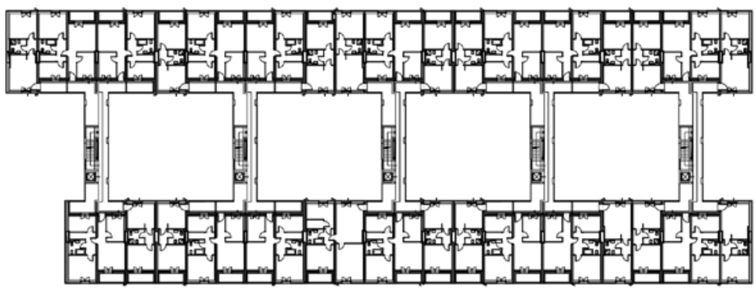

Figure 2 - Plan of the building type floor.

2. METHODOLOGY

During the renovation works, completed in 2014, a thermal energy meter was installed in each apartment, on the heating manifold; the meter consists of two Pt 500 temperature sensors (one on the supply circuit and one on the return circuit) and an ultrasonic volumetric flow meter (Table I). Hence the meter measures the thermal energy required to reach and maintain the value of air temperature set on the chrono-thermostat. The measured energy is net of the distribution efficiency of the part of the system placed inside the apartment (between the collector and the radiators), of the emission efficiency of the radiators and of the regulation efficiency (chrono-thermostat + thermostatic valves). On the basis of the values reported in the UNI TS 11300-2: 2014, a global efficiency of 98% can be estimated for this part of the heating system. The measured value corresponds approximatively to the "energy need for space heating" according to the terminology of ISO 52016-1: 2017.

Regarding environmental monitoring, since December 2016, temperature, humidity and CO_2 sensors have been installed in 17 apartments. They are placed in the corridor (Figure 3), in a barycentric position of the apartment, far from heat sources or thermal dispersions, at a height of 150 cm from the floor, at a side of the chrono-thermostat; it can therefore be assumed that the monitored air temperature corresponds to that which controls the operation of the heating system. In the monitored two-level apartments, an additional sensor was installed on the second floor. The technical characteristics of the sensors are reported in Table I.

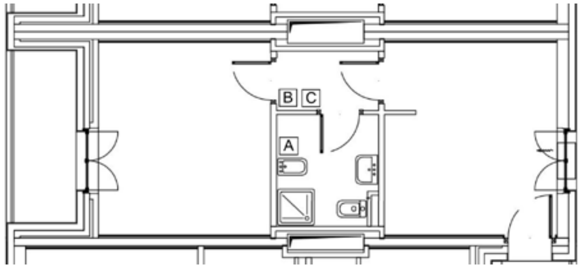

Figure 3 - Plan of the typical two-room apartment, with position of the energy meter (A), of the chrono-thermostat (B) and of the sensors of environmental quality (C).

The environmental data are recorded hourly and can be accessed remotely by the Municipality and Politecnico through access to an online platform, protected by a password. At the moment the visualization of the data is not available for the tenants.

Table I - Technical characteristics of the sensors. (From: SVM, Capetti)

Energy meter: SVM F25	
Temperature sensor	Pt 500
Volumetric flow sensor	Class 2
Interval of temperature	15 – 130 °C
Resolution	1 kWh, 0.01 m^3

Indoor environment sensor: WineCap WSD00TH5CO			
	Temperature	Relative humidity	CO_2 concentration
Sensor type	NTC 10 kΩ	Capacitive	Infrared
Range	-10 °C – 60 °C	0% – 100% RH	0 – 5000 ppm
Accuracy	±0,2 °C in the interval 0 °C – 60 °C	±5% at 25 °C and 50% RH	< ±50 ppm in the interval 0 – 5000 ppm

Figure 4 shows the energy use for heating of all the apartments (except for missing data due to occasional sensor failures), in the heating seasons 2014-15, 2015-16, 2016-17 and 2017-18, normalized with respect to the heating degree days (HDD) of the respective seasons. The degree days have been calculated on an hourly basis, according to ISO 15927-6: 2007. “Heating season” here means the period from October 15 to April 15, according to the Italian laws n°10 of 9/1/1991 and DPR 412 of 26/8/1993 and subsequent amendments, as a period of operation of heating systems in buildings in the municipalities belonging to the climate zone "E", like Milan.

Table II summarizes the values for the four considered years. The normalization on the HDD does not contribute to reducing the variability between one season and another. In particular, between 2016-17 and 2017-18, there is a reduction in the degree days accompanied by an increase in energy use.

Table II – Average values of the energy use for heating (absolute and normalized to heating degree days).

	2014-15	2015-16	2016-17	2017-18	Average
kWh/(m² yr)	56	70	74	85	71
Heating degree days (HDD)	1906	1955	1973	2154	1997
kWh/(m² yr HDD)	0.029	0.036	0.037	0.040	0.035

Figure 5 and Figure 6 show the actual, not normalized energy use, respectively for the 2016-17 and 2017-18 heating seasons, for which data of the air temperatures measured in the respective apartments are also available. The values are sorted by increasing energy use, together with the corresponding temperatures, whose statistical distributions are represented by a box-and-whisker graph. In this graph, the quartiles are indicated by blue bars (first quartile, q_1, second quartile, or median, q_2, and third quartile, q_3) and the maximum and minimum values, included respectively in the interval $[q_3 + 1.5 * (q_3 – q_1)]$ and $[q_3 – 1.5 * (q_3 – q_1)]$, are represented as whiskers above and below the quartiles. For apartments on 2 levels, where two sensors were installed - one for each floor - the arithmetic average temperatures were calculated hour by hour, and then the statistical analysis was performed.

A long-term comfort analysis was also performed based on the air temperature values measured in the apartments during winters 2016-17 and 2017-18. Adopting the Fanger model and the temperature limits indicated by the EN 15251 standard to define the ranges of the four categories of comfort in the residential area (from I, the one intended for environments with fragile people, II for new buildings, III for existing buildings, to IV, the least stringent), the hours when the air temperature falls in the various categories were counted, comparing them to the total number of hours in the considered period, thus obtaining the percentages shown in Figure 6. The particular indicator of long comfort period thus obtained is called Percentage Outside Range; this indicator, as it is defined, is not able to assess the extent of discomfort due to overheating within the IV category (Carlucci et al., 2014). According to the way the comfort categories in the residential sector are defined in the EN 15251, moreover, the upper limits of the categories I, II and III coincide (to the value 25 °C), therefore there is a direct switch from cat. I to cat. IV. The graph (Figure 7) shows that, although conditions in most of the apartments fall most of the time into category II as required by the standard[1], there are also six situations (related to four apartments) characterized by overheating with respect to category II.

[1] EN 15251 Annex G: "The different parameters for the indoor environment of the building meet the criteria of a specified category when: the parameter in the rooms representing 95% of the occupied space is not more than for example 3% (or 5%) of occupied hours a day, a week, a month and a year outside the limits of the specified category […]".

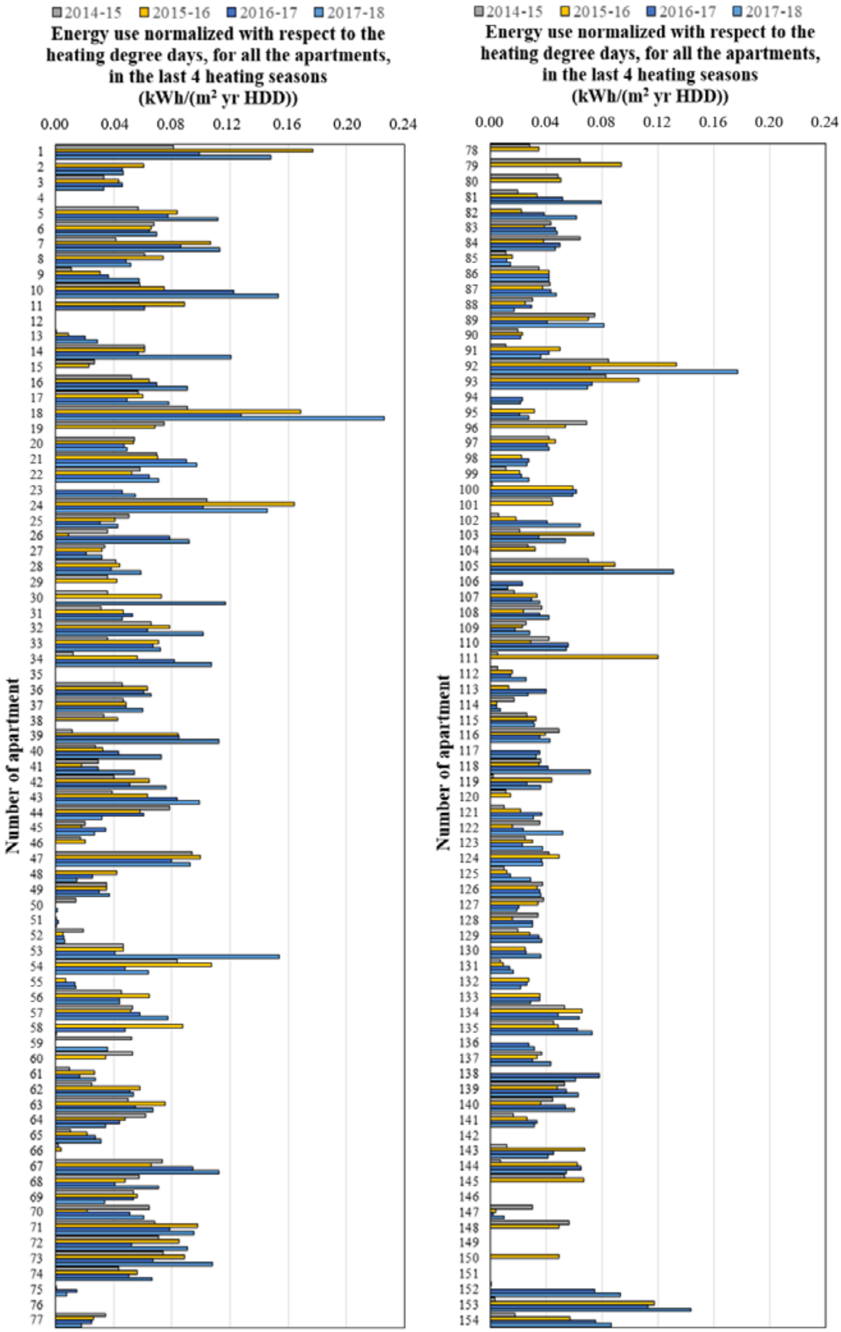

Figure 4 – Energy measured by the meters placed at the entrance of each apartment, normalized with respect to the degree days, for all the apartments, in the last four heating seasons.

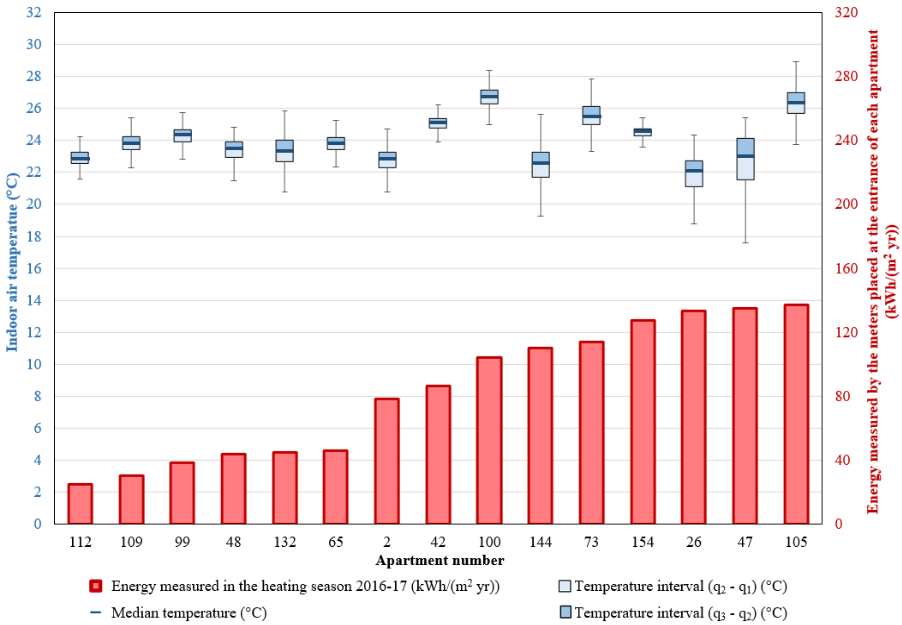

Figure 5 – Heating season 2016-17: energy measured by the meters placed at the entrance of each apartment and temperatures in the corresponding apartments.

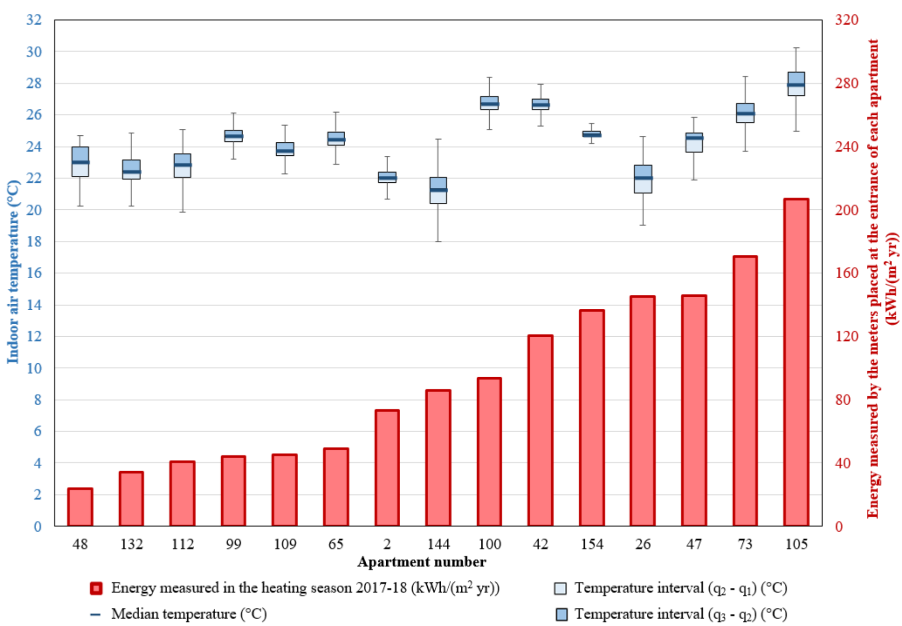

Figure 6 – Heating season 2017-18: energy measured by the meters placed at the entrance of each apartment and temperatures in the corresponding apartments.

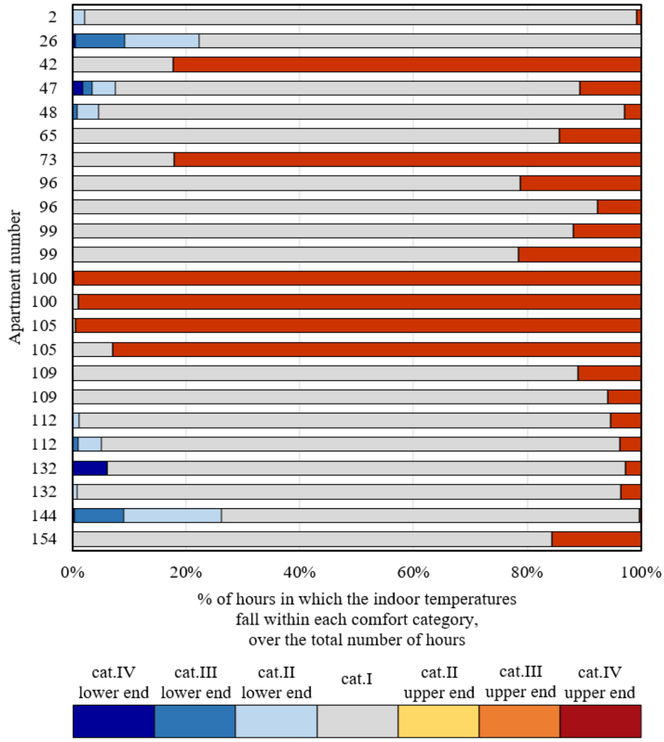

Figure 7 – Percentage distribution of hours in the various comfort categories during the heating period 2016-17 and 2017-18 (total data) for the apartments where the indoor air temperature sensors were installed. Situations where temperature is comprised between the upper limit of the cat. N-1 and the upper limit of cat. N are labelled by "upper end" and situations where temperature is comprised between the lower limit of the cat. N and the lower limit of cat. N-1 are labelled by "lower end". E.g. "cat.II lower end" means that the temperature is between the lower limit of cat. II and the lower limit of cat. I.

In parallel to physical measurements, information has been collected about the tenants' habits. The information was collected with an ethnographic approach by conducting semi-structured interviews to a sample of tenants, as well as conversations at different levels of formalization (e.g. scheduled meetings, unscheduled visits) and occasional observations with different levels of participation by the researchers. At the time of writing this article, the interview was conducted with six resident family units, five of which were selected among those living in the 17 apartments equipped with environmental sensors and who expressed availability to collaborate with the researchers. The sampling operation was initially aiming to an equitable representation for the placement of the apartment (floor, exposure), size of the family (single, couple, family with children), nationality. The selected people were asked to participate to an interview lasting about 60 minutes in their home, on a voluntary basis (without reimbursement) and according to their time preferences (date and hour). Several ones have declined the invitation, especially among families of foreign origin. In order to avoid over-representation of domestic habits and practices by the same type of families that agreed to be interviewed (typically small families of Italian origin), the sample is currently being expanded towards families of foreign origin, although residing in apartments without the aforementioned environmental sensors.

From a preliminary analysis of the interviews through the use of the NVivo software, it is evident a wide variability of social practices and perceptions of thermal comfort, as might be expected. The difficulty in understanding how the building systems work and how to maintain the ideal temperature in the home is common, and it influences the interaction with chrono-thermostat, thermostatic valves, windows and accessory devices to achieve the ideal temperature, both in summer and in winter.

4. DISCUSSION OF THE RESULTS

Observing the data, it is evident the presence of very high values of energy use and internal temperatures in some apartments. It is also evident that energy use variability is higher than expected (a variability is expected, even in high-performance buildings (Feist et al., 2001), but in the case analyzed here the variability is of an order of magnitude). Thirdly, the average value of energy use measured by the energy meters, 71 kWh/(m^2 year) (Table II), is far from the corresponding value estimated on the basis of the energy certification, equal to 34 kWh/(m^2 year) (calculated starting from the primary energy use provided by the certification, divided by 0.8 – primary energy factor for district heating declared by the supplier – and multiplied by 0.8, assuming 20% of heat losses between the thermal power plant and the apartment collector).

With regard to the variability in the values of energy use per m^2 of apartments, the main factors that are candidate explanatory variables for this variability within the same heating season are the following: (i) among those related to user behavior, the set point temperature and the operating times set by the user on the chrono-thermostat, in addition to habits such as keeping the windows open or not, not setting the thermostat to a lower temperature during periods of absence, etc.; (ii) the discontinuous occupation of some apartments (change of tenants during the heating season); (iii) the spatial orientation of the apartment; (iv) the position of the apartment inside the building (i.e. on the top floor or on the ground floor, or on the first floor above the entrance halls, or corner apartment: all situations in which there is a larger surface in contact with the external environment).

In a refurbished building with a high energy standard, such as the one under analysis, and assuming a correct execution of the works, supervised by an experienced project management team, it is unlikely that the geometric factors (exposure and location of the apartments) can justify differences of an order of magnitude in energy use per m^2 between different apartments.

The hypotheses that can explain a variability between the energy use of apartments on different years are the variation of outdoor temperatures during different winters, the variation of the occupation of the housing (e.g. empty apartment for part of the heating season) and the variation of the user behavior. Regarding the first hypothesis, the increase in energy use in the 2017-18 season, compared to the previous one, appears to be correlated with climatic data, since there is a simultaneous increase in the heating degree days (Table II). The second hypothesis seems valid for the 2014-15 season, which records the lowest energy use, but without complete occupation of the building. Indeed, according to the data provided by the building manager, the apartments were progressively assigned during the last months of 2014. Since then, they remained occupied almost continuously, by the same families. Other changes in user behavior in past seasons remain mostly unknown and are currently being investigated, but with the obvious limitations related to subjective vision, privacy restrictions, etc.

With regard to the deviation between the measured energy use and the value of the energy certification, in this comparison it should be noted that the certification does not aim to accurately predict building energy use, but to compare different buildings on the basis of standardized use assumptions. The calculation method (referring, for the considered case, to the legislation prior to the national law DM 26/6/2015) provides for the adoption of conventional use profiles (therefore obviously different from the specific cases), standard climatic data, continuous systems operation, fixed set point at 20 °C, "quasi-stationary" method. Some of these calculation hypotheses may lead to overestimation of the results, however the set point temperature used in the calculations is considerably and systematically lower than the one found in the apartments (and due to user settings); the presence of a much greater temperature difference between indoors and outdoors than assumed during the certification obviously leads to an increase in the energy use in reality; in the case in analysis, this effect seems to prevail over the others.

Finally, as in any monitoring campaign, the hypothesis of sensor failure must be considered. Therefore, technical checks were carried out on a sample of the sensors, which confirmed their correct functioning. A systematic check of all the meters has been planned by the Municipality under request of the research team of EnerPOP and should take place at the beginning of 2019.

The three hypotheses outlined above, aimed at explaining the discrepancy between calculated and monitored energy use, both in terms of variability and magnitude, all underpin the importance of the role of the occupants. The EnerPOP project starts from this observation and intends to leverage some aspects, or drivers, to get more attention to energy use by the tenants. These drivers can be classified mainly into three categories: economic, ethical and emotional. The economic driver requires that a reduction in energy use is accompanied by a proportional, or better, more than proportional (through incentive schemes) reduction in energy bills. This driver cannot be easily activated at the moment, given that in the current configuration the tenants do not pay based on their actual energy use, but on total energy use subdivided according to the floor surface of the apartment.

The ethical driver calls upon the environmental awareness of individuals, possibly cultivated through appropriate awareness campaigns, on the issues of global warming, CO_2 emissions, sustainability in general. These activities are underway in the EnerPOP project, for example through a small exhibition of good practices in managing the ideal temperature in summer and winter, saving money and stress at the same time. Also the technical information on the refurbishment occurred in the building and on the technological innovativeness of the installed systems, carried out both in EnerPOP and in EU-GUGLE, is part of this effort, and it aims to create a feeling of pride and community, leading to the adoption of sustainable practices in order to maintain the performance and quality of the building. This driver relies on immaterial values, and as such can be difficult to apply in disadvantaged contexts, where economic precariousness, the definition

of individual priorities that go beyond those of the community and the presence of conflicting social dynamics (exacerbated by economic precariousness) tend to overshadow other aspects, unless there is a strong personal motivation by the individuals.
Finally, there is the emotional element, which aims at involving users by resorting, for example, to entertaining forms of participation. In particular, young people could appreciate the possibility to view the measurements of the sensors in real time or almost in real time, together with the data history, through a simple and effective interface, in order to receive immediate feedback and gratification to their actions in terms of energy saving. Social aspects, such as competitions related to energy saving, or in a broad sense of sustainable practices, may be explored as well. The criteria could be the same as those already presented for incentive schemes of the energy provider (normalization with respect to the apartment area, correction factors for exposure and position), or the reward could just be a supplier bonus (besides, obviously, the savings already achieved). This would be a way to reconcile the three different drivers described so far. The possibility to visualize one's own data (energetic and environmental) might inspire interest and curiosity and it would probably be an incentive to the involvement of the tenants, and possibly also to the change of energy-intensive practices. The scarcity of available funds, the need and timing of coordination between building owner and manager, the complexity of some non-standardized procurement procedures for services like detailed monitoring, etc., have till now prevented this line of action to be pursued. The difficulties might be overcome in the next months with a strong commitment of the owner and the manager to make this project a real forerunner for future actions.
Other ongoing actions rely on the emotional component of pride and sense of belonging. Tenants are involved in participated and co-designed activities in which they may feel as an active part, therefore co-constructors and co-managers, tending towards common interests. The aforementioned exhibition that involves the participation of the tenants themselves as actors, or the activation of interest groups to facilitate the exchange of information in the long term, are examples of this strategy.
The one listed above are working hypothesis for the promotion of potential changes in practices that are often routine and therefore consolidated, for which it is difficult to foresee a change in the short term, and it is consequently difficult to expect a quick effectiveness in terms of energy savings.
The planned operations include a process of acquisition of information and also of knowledge of the social context, in order to adapt general strategies to specific conditions according to an iterative process that hopes to get closer and closer to the tenants, i.e. the energy users.

5. CONCLUSIONS

From this first phase of field research, it clearly emerges how the actual energy use of a building and the connected energy costs (often paid by the Municipality, in ERP contexts) may present significant deviations in comparison to the values estimated during the design phase, even in case of careful design and energy modeling, according to standards and protocols and careful execution of the retrofit work.

The actual behavior of the inhabitants and the practices carried out in the apartments might be major drivers of a significant difference between calculated and actual energy use. The current and future activities of the project aim at a more detailed definition of the practices conducted in the homes by the tenants, increasing the representativeness of the descriptions provided, and at an identification of patterns of habits, needs, perceptions of comfort, cultural factors which might provide explanatory variables of the variations in energy use. Finally, it is foreseen to develop actions to support tenants to identify and modify inefficient practices, with a process focused on participation and empowerment.

6. AKNOWLEDGMENTS

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